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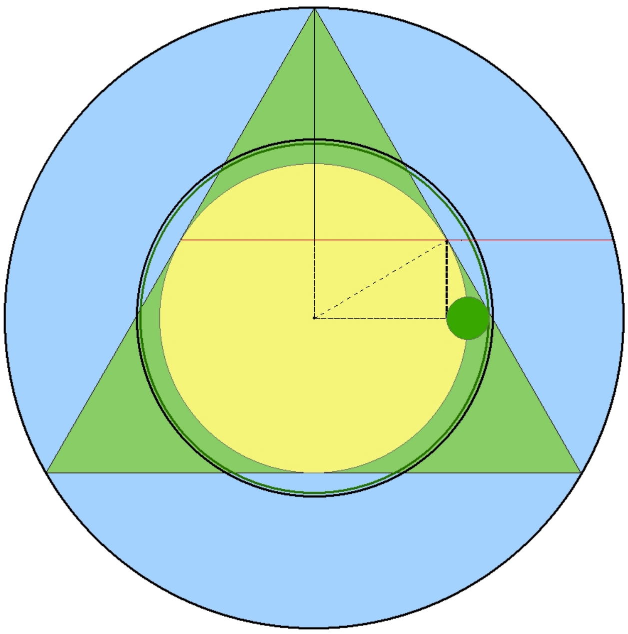
Assessment and Modeling of Available Forest Resources in Europe for Energy Supply

Final Report

Vasyl Myastkivskyy



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Preface

The main sources of information for an assessment of available forest wood resources in Europe were The MCPFE Report on Sustainable Forest Management in Europe "State of Europe's Forests 2007" and Forestry Statistics from UNECE [http://w3.unece.org/pxweb/database/stat/Timber.stat.asp].

In some cases the information in this report is given in a very simplified form. In the methodological part, for example, the silvicultural and physiological basics of tree growth have been not deeply explained. In general this paper should not be seen as a scientific publication but as scientific support for the working program.

1 Introduction

…Forest is more than only the trees
And trees are more than only wood…

Forest is one of the main and - from a human point of view - most valuable natural resources of the European continent. Its first and most important role is ecological. This includes regulation of water and temperature regime, maintenance of soil stability and fertility, carbon stock managing etc. We can assume in general that forests sustain the ecological productivity of the European continent.

Wood supply (read also energy supply) is a second valuable role of European forests. Energy value is only one part (although a very important one) of woody biomass overall value.

Almost all projects that have ever dealt with the question of availability and the further use of forest wood resources (biomass) were developed with the emphasis on sustainable use of this renewable resource. Estimation of wood resources availability for further economical growth was made mostly from a human point of view and on a demand-supply basis. It means that, even if ecological and economical values of the forest ecosystem as a whole were considered on equal terms at the beginning of research, the difficulties of estimating ecological values with respect to monetary values has tended to lead to an overestimating of resources available for "economical use" (wood supply) and an undervaluing of ecological "goods" of forests at the end of research [http://www.fao.org/docrep/008/ae428e/ae428e04.htm].

Considering our need to adapt to climate change, the assessment of available forest wood resources in Europe will be made in this project from a so-called forest ecosystem point of view. It means that predominance of the ecological values of the forest ecosystem over its economical values will be seen as an axiom throughout this research. This is the core point of the methodology and results presented here.

Theoretically for the purpose of our research it would be enough to know the distribution of site indexes and age structure or height of stands to be able to predict potential wood supply from European forests. In reality there is at least one other important notion which varies significantly from country to country and from stand to stand and which can lead to big uncertainties in such estimations. This notion is forest management practice.

Unfortunately we do not have information about site index distribution and age structure or height of stands; neither are we familiar with country specific forest management rules and traditions. But, there are other values which reflect the combined result of both site index distribution and forest management practice. These values are Net Annual Increment (NAI) and percentage of NAI use. Both of them are available from the MCPFE Report "State of Europe's forests 2007" and will be used in this research.

2 Methodology

The way from primary energy of sun shine to energy conserved in biomass is long…

2.1 General overview of possible ecosystem reactions to changes in site conditions

2.1.1 Common notions as an introduction into the field of ecological research

The first definition of the term “Ecology” dates from 1866 by Ernst Haeckel, a German biologist and supporter of Darwinism, and it comes from οίκος – Greek oikos “house, household”, and λόγος – Greek logos “knowledge”, meaning – “science of household”. In 1866 Haeckel wrote: “Under Ecology we understand the whole science of the relations of the organism to the surrounding outer world, where we can expect in the broader sense all conditions of existence. These are partly organic and partly inorganic nature” [1] (http://de.wikipedia.org/wiki/%C3%96kologie, with changes).

The main functional units in ecology are ecosystems. Not ”unit” and not “ecosystem”, but the plural form of these notions. This interpretation comes from the definition of Ecology: relations of the organism to the surrounding outer world and (not mentioned in definition but existing) surrounded internal world.

A graphical illustration of such an ecosystem with surrounding and surrounded worlds (complex of neighbour-ecosystems) is presented in Figure 1. Two dimensional bodies on the graph represent at least three dimensional entities in fact.

Figure 1 explains in simplified form the functioning of a theoretically separated unit of three ecosystems. The equilateral triangle in the figure represents an ecosystem (for example, a forest stand) which is supposed to be in or near to balance. The internal circle represents ecosystems or organisms (surrounded internal world which consists, for example, of trees) which belong to the forest ecosystem. The external circle represents the surrounding neighbor-ecosystems (e.g. agricultural fields, water reservoirs, settlements etc.) which influence the forest ecosystem (triangle) by biotic, abiotic, and anthropogenic ecological factors.

These ecosystems are linked by exchange of different products of metabolism and / or exchange of energy.

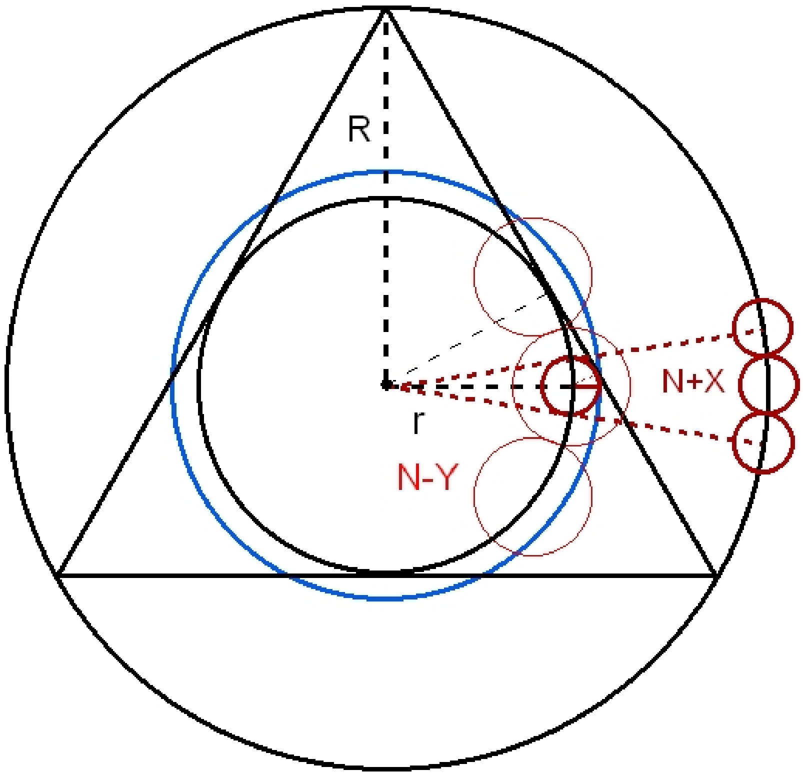

Figure 1: Ecosystem (equilateral triangle) aiming to balance with surrounding and surrounded complex of neighbour-ecosystems (external and internal black circles)

If we accept that all this complex of ecosystems stays in balance, then we can accept that all of its parts (organisms) have the same exchange of energy and the same size (e.g. small red circle on the black internal one). In this case the *N*-number of red circles on the internal surrounded black circle will be influenced by the (*N* + *X*)-number of the same sized red circles on the external surrounding black circle. Such a positioning leads to “overproduction of products of metabolism” on the external surrounding circle side and to an imbalance in its energy exchange with the internal surrounded circle.

This inequality is the base for an increasing of productivity of N-number organisms of the surrounded ecosystem to the level of production that will cover the difference in overproduction by X-number organisms of the surrounding ecosystem.

An increase in productivity will lead to an increase in size (big red circle) of organisms on the border of our surrounded (internal red circle) complex. Such an increase in size with time (Growth) restores balance between neighbour-ecosystems (external surrounding and internal surrounded circles) but forms the basis for imbalances inside the surrounded N-number complex itself (growth will lead to decrease of Y-number of organisms on surrounded circle).

These imbalances lead to a decrease of area (and resources) available for internal N-number components (e.g. trees) inside the surrounded ecosystem. As a result the balance between external surrounding ecosystem with (N + X)-number of organisms and internal surrounded ecosystem with (N-Y)-number of organisms will be achieved (even if for a short period of time).

Figure 1 explains not only the complex of ecosystems aiming (staying is not an appropriate word here) to be in balance, but also growing or disappearing organisms which are parts of ecosystems and, at the same time, ecosystems themselves.

Figure 1 can also be seen as a very simplified but still valid schema for increasing (growing) or decreasing (disappearing) organisms. The theoretical border between Growth and Disappearance is marked by the blue circle. Continuing movement of this blue circle in the direction of the surrounding ecosystems means that N-number of organisms on the internal black circle (surrounded ecosystems) are able to grow more efficiently compared with the (N + X)-number of organisms on the external black circle (surrounding ecosystems).

The inability of surrounded ecosystems to be more efficient (Vital) compared to surrounding ecosystems will lead to a decrease with possible disappearance all of these systems or their parts in the future if this trend towards the centre of the surrounded ecosystems complex continues permanently.

Such an interpretation of increase (growth) and decrease (disappearance) of organisms (or ecosystems) applied to our research leads to conclusions connected directly to the question of percentage of use of growing and renewable forest resources (wood).

Let us accept that, surrounded by the internal black circle ecosystem is a forest stand with growing stock r in 2009, and that this forest stand will have growing stock R in 2010 (surrounding external circle, please see Figure 1). Then the difference (R – r) is the annual increment that we are going to use. In case of 100 % use of real available biomass we will cross the stand's "blue line" which in fact marks its appropriate border of ecological sustainability, or in other words, the optimal level for resistance to unfavourable external and internal disturbances.

To summarize, we can assume that **it is not eligible from an ecological point of view to use all 100% of annual increment**. The level of sustainable use of wood resources varies in fact and depends on internal and external conditions, and the forest stands' ability to react by growth to changes in these conditions. Foresters aim to maintain this growth at a stable level or to improve it.

2.1.2 Reactions of (forest) ecosystems to changes in site conditions

Sustainable use of forest wood resources can be defined to mean the use of such an amount of wood as can be recovered by the forest. We have to rethink this notion of sustainability. As shown in the previous chapter, the amount of wood being taken from forest ecosystem cannot be equal to annual increment. Depending on site conditions (summarized influence of internal and external ecological factors) and the vitality of forest ecosystem itself as a whole, the percentage of ecologically sustainable use of annual increment can vary significantly.

Forest ecosystems that are sufficiently supplied by those ecological factors most important for them (soil fertility, microclimate, water-temperature balance etc.) will be more productive and will have more vigorous growth. It will be possible to use almost all the annual increment from such forests. Under a positive development trend of site conditions, even an overexploited forest stand is able to recover.

Conversely, in the case of an insufficient supply of ecological factors (even some of them) or negative trend in its development, overexploitation of forest stands will lead to additional loss of their actual and future productivity.

It is appropriate to talk here about future productivity while we deal with an open system. Each site has its own potential productivity “ensured” by given site conditions (ecological factors). Insufficient growth of the surrounded system leads to underuse of ecological factors “supplied” by surrounding ecosystems. Such disproportional energy exchanges at the border between the surrounded circle and the triangle provide imbalances at the border between the triangle and surrounding circle (please see Figure 1). Constant internal imbalances combined with a continued unfavourable influence of external ecological factors are the sources of ecosystem degradation or disappearance.

This is valid not only for forest ecosystems. Figure 2 in very simplified form presents some more or less tightly connected units of ecosystems. We have to accept the fact that these open neighbour-ecosystems and units are tightly connected.

Figure 2 (a) presents the idea explained in Chapter 2.1.1 in another form. In this case in the place of the surrounded ecosystems is Economy; the triangle represents Human Society and surrounding ecosystems – Forest Stand. Dashed lines “Demand-Supply” mark the sustainable level of use of the ecosystems’ annual additional product (increment). Two red circles on Figure 2 (a) mark the critical level of use shown in Figure 1 as a red circle. Human Society is placed in a central position of the unit of ecosystems shown in Figure 2 (a). From this position we are not able to observe the whole numbers of processes going on at the base of the Forest Stand ecosystem.

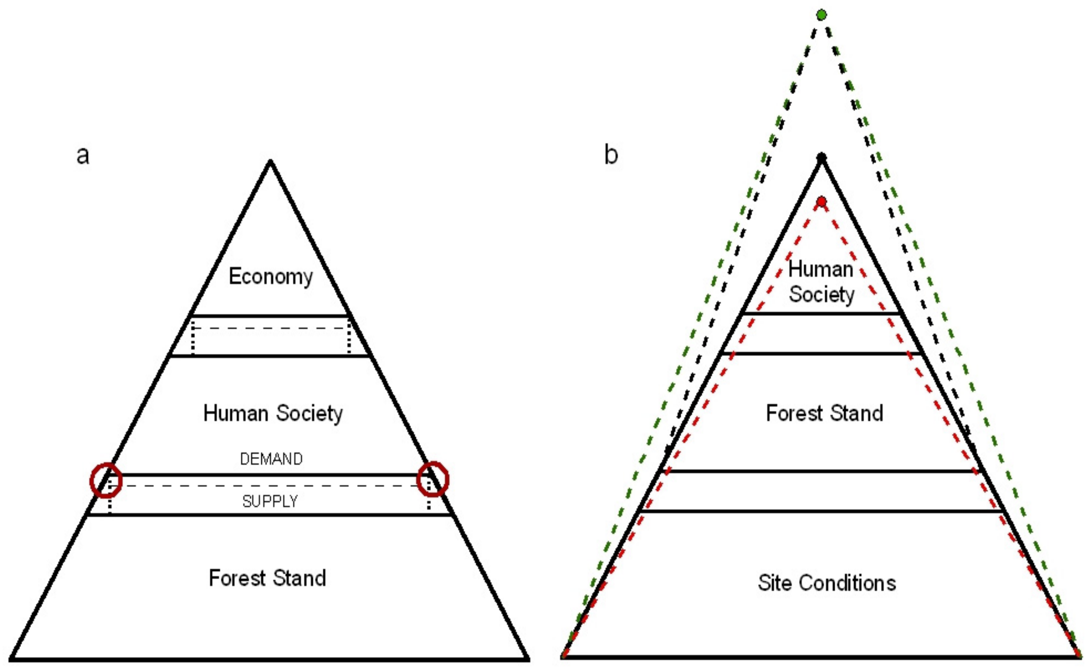

Figure 2: Units of connected ecosystems (a) and change of their productivity by changing site conditions (b)

In Figure 2 (b) the Forest Stand becomes the central position and can be seen as the triangle in Figure 1. Site Conditions and Human Society play the roles of surrounding and surrounded ecosystem units and these roles, depending on our point of view on the forest ecosystem, can be changed. This “replacement” of the Forest Stand ecosystem into the central position (Figure 2 (b)) is necessary for understanding the trends in development of surrounding and surrounded ecosystems and the level of influences of these trends on Forest Stand condition.

The triangles in Figure 2 are equilateral triangles, which mean that this entire complex is near to balance. But we know that this is only a theoretical balance. Positive or negative trends in Site Conditions changes will lead to positive or negative changes in total complex productivity. These positive and negative changes are shown by green and red dashed lines in Figure 2 (b). Following the development of the coloured lines we come to the conclusion that **even small changes in site conditions can lead to a huge increase or decrease in productivity of the whole complex of surrounded ecosystems**. Improving a Forest Stand’s internal ecological factors by theoretical stable Site Conditions will also lead to a productivity increase in systems located above (please see black dashed lines from the base of Forest Stand to the green dot on the top of Figure 2 (b)).

2.1.3 Ecologically sustainable use of annual increment

As noted in the two previous sub-chapters, the level of annual increment (AI) use cannot be equal to 100% and will depend on the ecosystem's unit productivity. It has already been mentioned that surrounding ecosystems, surrounded ecosystems and between them the border ecosystem itself (Forest Stand as ecosystem under research) belong to this unit.

An ecologically sustainable level of annual increment use means such a level of artificial forest ecosystem disturbance that will not create an imbalance with surrounded and surrounding ecosystem units that enables deterioration of forest ecosystem productivity in future. It means that level of border ecosystem use should be less than or equal (!?) to the level of irreversible imbalances between the border ecosystem and its surrounding and surrounded neighbour-ecosystems.

Figure 3 presents an attempt to explain the theoretical level of annual increment use on an ecologically sustainable basis.

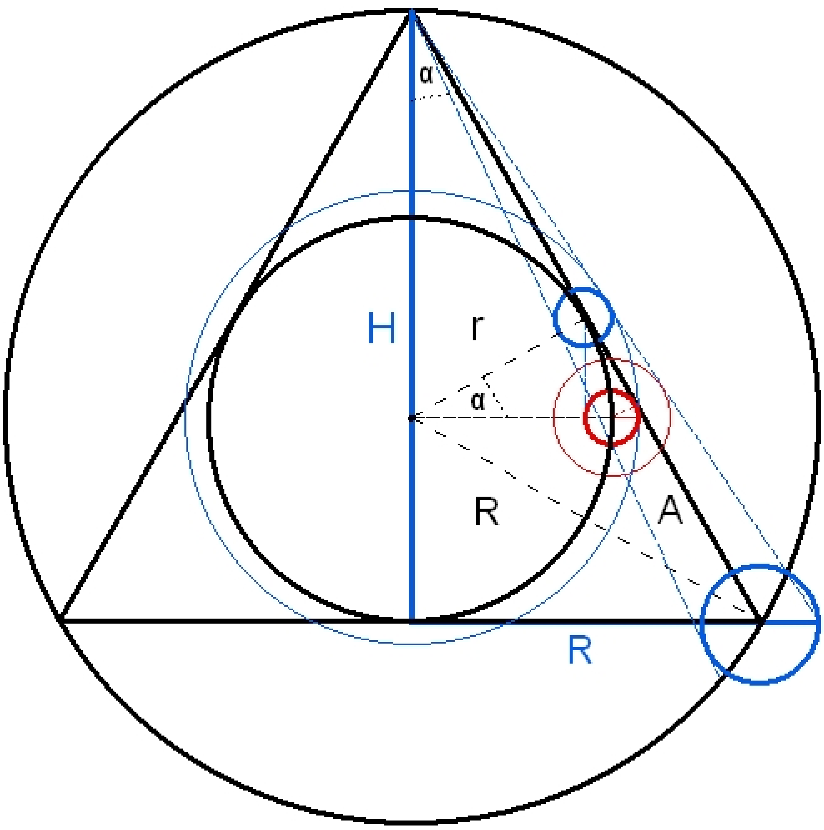

Figure 3: Principle of estimation of ecologically sustainable percentage of annual increment use

As already introduced in Chapter 2.1.1 the ecosystem units shown in Figure 3 aim to be in balance. This means that the border ecosystem must possess an amount of energy equal (or almost equal) to the amount of energy acting on it from both the opposing surrounded and surrounding ecosystems units. If the surrounded ecosystems' energy is r and the surrounding ecosystems' energy is R, then total energy of ecosystems unit will be (R + r) or equal to the height of triangle H.

We accepted that our ecosystems complex aims to be in balance. This means automatically that the border ecosystem (Forest Stand) has to be able to resist continually the imbalances with surrounding ecosystems (please see explanation in Chapter 2.1.1) and maintain the balance of its own surrounded ecosystems (red circles in Figure 1 and Figure 3). Applying *Le Chatelier-Braun principle (1884)* to our case we can say that ecosystem action aiming to achieve equilibrium is shifted in the direction in which the effect of external influence is weakened. The small blue circle in Figure 3 marks the position in which opposite reactions between surrounded-border and border-surrounding ecosystems are weakest, and are equal to (r + r) or R. Under these conditions, an energy amount of 2r on the ecosystems border can be related to the total unit's energy of 3r (H = (R + r) = (r + r + r) and so H = 3r), and the balance of the whole ecosystems complex will be maintained.

This means that if the whole ecosystems unit is in balance (theoretically!!!) it will be feasible (sustainable from an ecological point of view) to use not more than 2/3 of its increment without detriment to the whole complex productivity.
Applied to Forest Stand which was shown in Figure 3 as an equilateral triangle with site length A, it makes sense to use following formula:

$$R : H = \frac{\sqrt{3}}{3} A : \frac{\sqrt{3}}{2} A$$

After solving this proportion we will come to result that R is equal to 2/3 H (please see blue lines in triangle and blue letters R and H in Figure 3).

In this explanation it was accepted that the entire imagined ecosystems complex is continually aiming to be in balance. In reality this is surely not the case. We always have to deal with changing site conditions which can lead to imbalances some points of the surrounded, surrounding and / or border ecosystems.

If after the use of 67% of annual increment, the forest stand ecosystem is able to come back to balance, then it means that two positive trended units were able to recover losses from a third negative influenced unit (we have disturbed our triangle unit through using its annual increment). So then for two negative trended units it will be eligible to use $0.67^2 \times 100 = 45\%$ and for all three negative trended units it will be eligible to use $0.67^3 \times 100 = 30\%$ of annual increment.

2.2 Common notions as an introduction in the field of forestry

2.2.1. Growing conditions, site index and biometrical parameters of trees

In a very simplified form forests can be seen as dominated by communities of organisms (trees) at the border between Lithosphere and Atmosphere. From a human point of view these communities are the most remarkable parts of the Biosphere, and they have their own composition, structure and size. Species composition, structure of forests and size of trees in forests are mostly influenced by three main components: temperature regime, water regime, and availability of nutritive elements. Different combinations of these components in forest science and practice are expressed through site conditions or forest growing conditions. Long term growing conditions combined with successive short term disturbing factors (biotic, abiotic or anthropogenic) form the basis of existing forest site indexes.

It belongs to basics of forestry that site index will be estimated through stand height at a given age. But a stand consists of a number (N) of trees and this number varies with site index and age of the stand. The number of trees at a given age and in a given area can play a crucial role in particular for interspecific and intraspecific competition. As a result of this competition, the forest stand will have a specific spatial structure, and as result of this spatial structure the stand will be populated by trees with corresponding biometrical parameters (height, DBH, stem form etc.).

Figure 4 [2] presents in visual form the above described connections between the spatial structure of the stand and biometrical parameters of trees. Of course this is a very simplified explanation but it helps to understand the difference in biometrical parameters by trees which have been grown with continuous competition for space (in forest) and without this competition (on field – open place).

It is also very important to underline that these trees are the same age and have been grown (we have to imagine this theoretical case) under the same “external” site conditions (please see Figure 4).

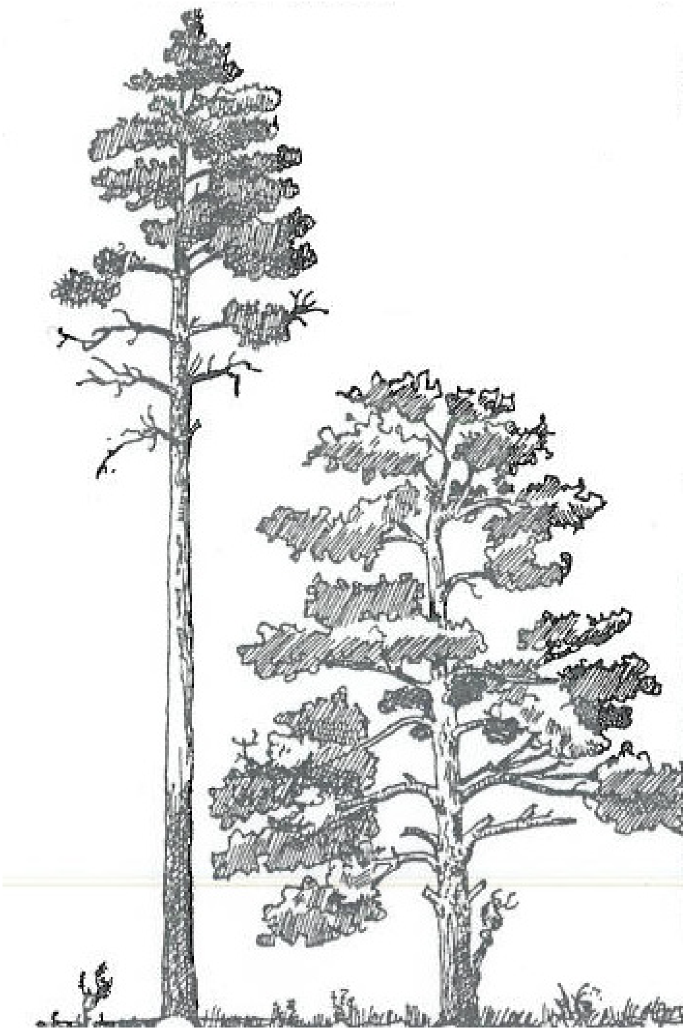

Figure 4: Height and shape form of pine (*Pinus silvestris* L.) trees of the same age, which have been grown in forest (left side) and in an open place (right side) (Picture is taken from [2])

Trees with the shape forms presented in Figure 4 can be found in the same stand, especially if we deal with mixed uneven aged stands. And it could be explained through specific (genetic, microclimatic, soil etc.) conditions. But in our case we are going to avoid such a complex situation so as to be able to make a clear explanation of the method which will be further developed and presented in this Report.

2.2.2 “Spatial backgrounds” in tree’s growing process

Let us imagine a hypothetical situation in which an organism (in our case tree) can grow undisturbed in all directions. It means that the organism gets the same resistance from all sides and, at the same time, this organism will receive sufficient energy (or nutritive elements) to enable it to grow in all directions with continuously increasing vigour. Such an imaginary situation is presented at the left side of Figure 5.

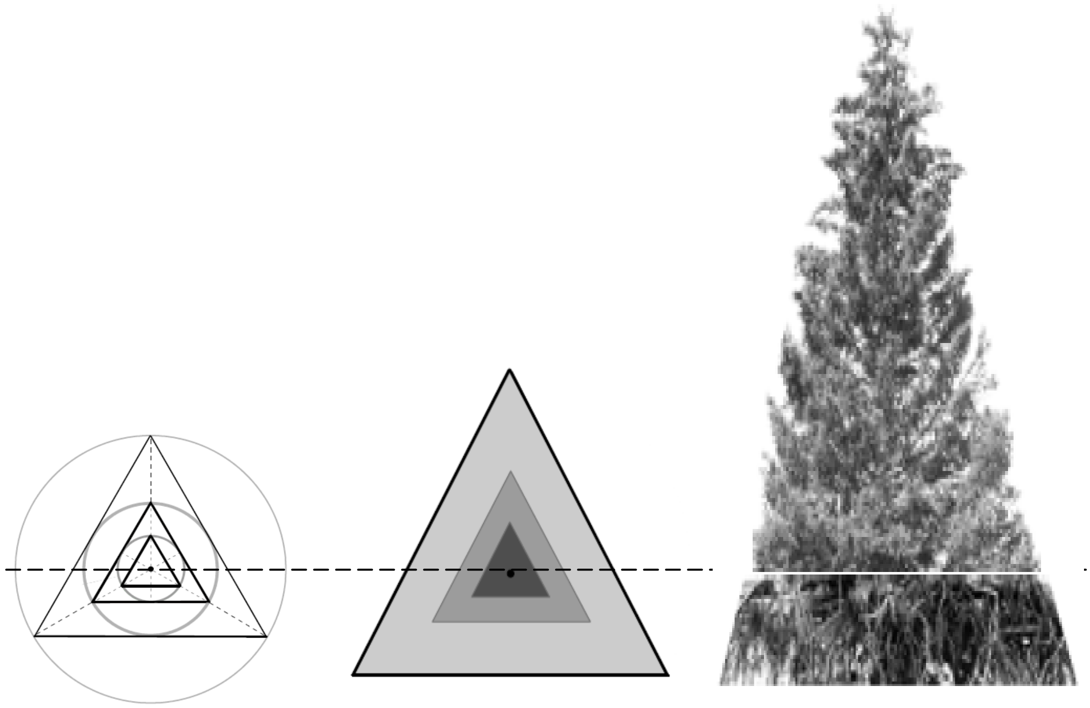

Figure 5: Connection of tree’s growing process with the abstract graphics presented in Chapter 2.1 (for further explanations please see Fig. 6)

The abstract graphic at the left side of Figure 5 corresponds to the graphic presented in Figure 1 on page 12. The triangle in the middle should be seen as the connection between the graphic on the left side with the tree shape (*Piceae pungens* E.; Source: http://de.wikipedia.org/wiki/Stech-Fichte, with changes) on the right side of Figure 5. The dotted line here marks the earth’s surface. Figure 5 presents a theoretically almost undisturbed growth of the organism (in this particular case – tree) in all directions. In reality this is not the case. The near to real situation is roughly presented in Figure 6.

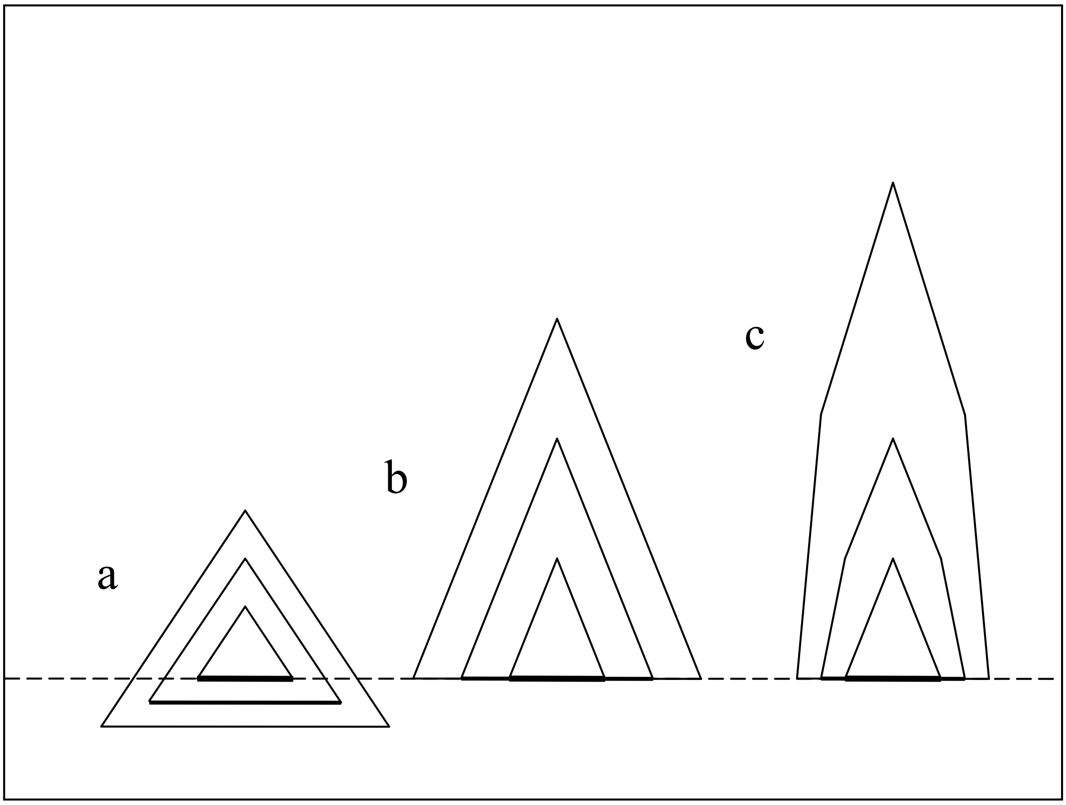

Figure 6: Connection of tree's growing process with the abstract graphics presented in Chapter 2.1 (for begin please see Figure 5)

The dotted line on Figure 6 marks again the earth's surface. Picture **a** (as connection to graphics shown on Figure 5) represents almost undisturbed growth in all directions.

In Chapter 2.1.3 *Le Chatelier-Braun principle (1884)* was mentioned. According to this principle a tree will grow in those directions where external influence (resistance) is weakened. In the case presented here it will be in a vertical direction upwards from the soil surface (please see Picture **b**). In a forest stand this growth is positively influenced by neighbouring trees growing nearby. As a result of growth the competition for space, light and nutritive elements will increase, and this will lead to the self-thinning process well known in forestry. All factors mentioned here, namely: initial stand structure, availability of nutritive elements and self-thinning are reflected in tree form (spatial form of crown, stem, and root system) of surviving trees or average tree form which will represent the existing forest stand at this time and under these particular conditions. Picture **c** in Figure 6 represents an abstract stem form of a tree which has been grown under site conditions that caused it to form a taller and more valuable stem and a more compact root system (dimension of root systems are presented here by the size of bold lines on imaginary soil surface, please see Pictures **a**, **b** and **c** on Figure 6).

Figure 7: Forest sites productivity reflected in the forms of tree crowns and stems

Figure 7 connects forest sites productivity and the forms of tree crowns and stems. This Stand-Site connection can be interpreted as follows (please see also Figure 7): area covered by trees (horizontal surface – the base of cylinders) becomes its volumetric dimension (horizontal and vertical growth of trees – the volume of cylinders) according to given site conditions (ecological factors) which can be used by the trees of the stand for their growth. Intensity of this growth (forest stand productivity) is expressed through the height at a given age and it means for our interpretation (Figure 7) that stand productivity can be expressed by the ratio between the cylinder height and its base (or ratio between vertical and horizontal growth).

2.3 Correspondence of tree growing process to site conditions

It is a well known fact (and not only in forestry) that the dynamic of the growing process corresponds to given site conditions. In this chapter, once again, we will try to present this correspondence in abstract forms.

In Chapter 2.2.2 was assumed that stand productivity can also be expressed by the ratio between the height of a cylinder and its base (please see Figure 7). It has to be mentioned here that this ratio is connected to the H/D- ratio commonly used in forestry. As was emphasized in Chapter 2.1.2; to be able to describe and evaluate appropriately the processes ongoing at forest stand level we need look at forest ecosystems at the level of site conditions (please see Fig. 2 in Chapter 2.1.2).

The aim at this stage of the project is not to measure the volume of the stem or growing stock of the stand but to find the connections and dependences between these notions and site conditions. Some examples of these dependences are presented in Figure 8.

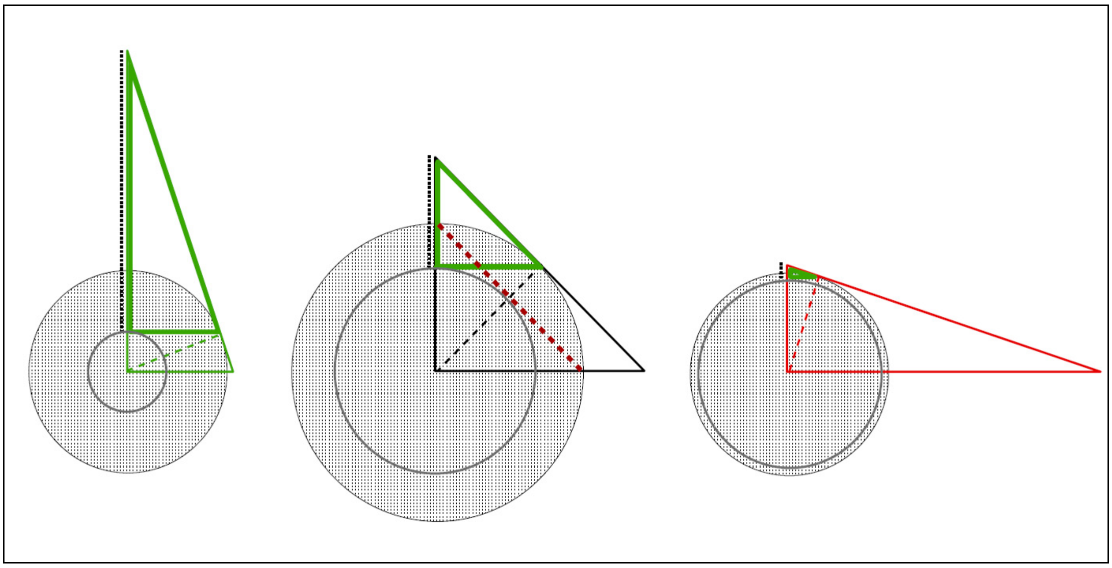

Figure 8: Graphical explanation of ecological sites productivity

Figure 8 explains in abstract graphical form the situation presented in Figure 7. The picture on the left side of Figure 8 corresponds to the picture on the left side of Figure 7. The internal circles in Figure 8 roughly represent the initial situation.

External circles represent increment in a horizontal direction. Vertical lines represent height and vertical green lines represent increment in a vertical direction. Dotted perpendiculars to the hypotenuse represent the direction in which growth will have the biggest resistance. In this interpretation, the picture at the left represents the biggest resistance from the sides which accelerate growth in the height – high productive forests; the picture in the middle represents "equal" growth in both vertical and horizontal directions – middle-low productive forests; and the picture on the right side represents highest resistance from above which means preferable growth in horizontal direction – shrubs and other wooded land. Green triangles and vertical black dotted lines represent increment in the plant community achieved under given site conditions. And part of this increment should be "invested back" into the ecosystem to maintain the basics of the sites' ecological productivity (which on the pictures are represented by the triangle bases: smaller base of triangle means higher productivity).

Beside explanation of ecological site productivity, Figure 8 aims to underline the following points important for this project:

- ecological research in general and this project in particular deals with a lot of continuously changing variables;
- these variables can be structured and presented in abstract forms (geometrical figures, growth directions etc.);
- abstract forms and mathematical dependences between them can be used for describing and modelling ongoing dynamic processes in ecosystem.

Tree growth is a dynamic process which has already been presented above in abstract form. The change in biometrical parameters of average trees with time will represent forest stand development under corresponding site conditions.

So, each forest stand can be represented by an average tree. It means that the abstract forms which have been used here for description of growth process at a separate tree level can also be used at forest stand level. If we can describe tree growing processes by mathematical dependences in changing the abstract forms described above, then we will be able to find mathematical rules in ecosystem dynamics.

Almost the same interpretation has been successfully used for the stands' growing stock estimation without yield tables [3]. The bases for growing stock estimation without yield tables and for estimation of percentage of sustainable wood resource use are the same: namely, correspondence between site conditions and stem form and the aim of dynamic processes in the (forest) ecosystem to come to balance.

We have accepted that stem form corresponds to given site conditions. Then for estimation of percentage of sustainable wood resource use we will need to know the "limiting balance" or such a level of use which will put the system at the border between ability or not to come back to balance. In other words we have to estimate the quantitative value of imbalance (percentage of use) which will lead to a change in qualitative value of the system (ecosystem degradation).

The problem in our situation is that we do not work with static systems. All our imaginary forest stands throughout Europe have different site conditions, age structure, management particularities and X-number of other variables.

In this case the only solution can be to find an abstract stable system and through mathematical dependence(s) calculate for it such limiting criteria (or conversely, “point of balance”) which step by step will lead this system into qualitative new positions. In this way we will be able to estimate the maximal possible sustainable level of forest ecosystem use, or, to be more precise, percentage of annual increment use from the stands growing in significantly different conditions.

2.4 Estimation of ecologically sustainable annual increment use

All the figures presented above are two dimensional. But in reality, as was already mentioned in Chapter 2.1.1, we deal with three dimensional bodies.

Taking into account these three dimensionalities of processes the base of cylinder and its height can be presented by two circles. If we go back to our imaginary situation of undisturbed above ground tree growth (Figure 5 and Figure 6) then we will come to the Figure 3 presented in Chapter 2.1.3 on page 16.

It should be underlined at this stage of the project that the information presented here in such a simple form is based on fundamental ecological science. Figure 3, for example, is directly connected to Yoda’s Rule (also called –3/2 power law) [4] and can be also explained through allometric relationships [5].

In Chapter 2.1.3, two thirds or 67% of annual increment was estimated as a sustainable level of AI use under stable growing conditions. The same principle of calculation was used there, namely, the ratio between horizontal and vertical growth (the base of cylinder to its height). It was also mentioned there that by positively directed growing conditions the percentage of annual increment use can be significantly higher or, conversely, under negative growing conditions, significantly lower.

For the purpose of our research we have to find the “point of balance” which marks the critical step from one qualitative situation of the system to another one. And this “point” in the unit-ecosystem represented in Figure 3 on page 16 is equal to

$\tan 30 \div (2/3) = 0.866025404$, where $2/3 = R / H$ and Angle $\alpha = 30°$

or

$0.5 \div \tan 30 = 0.866025404$, where $r = 0.5\ R$

or

$\cos 30 = 0.866025404$, where $r = 1$

It means that 86.6 % marks the “point of balance” in percentage of annual increment use. This number 0.866025404 or 86.6 % is very important for the ongoing project but not something “permanent” for the processes ongoing on ecosystem level. While ecosystems are dealing with different disturbing factors, not one but three basic numbers (or levels) will be proposed, marking the percentage of annual increment use:

maximal use = 93.1 % ($100 \times \sqrt{0.866025404} = 100 \times 0.930604859$)

maximal sustainable use = 86.6 % (100×0.866025404)

sustainable use = 75 % ($100 \times 0.866025404^2 = 100 \times 0.75$)

These three numbers, which have been derived from the above explained abstract forms and describe the functioning of (forest) ecosystem in theory, will be used for the estimation of a sustainable level of forest wood resource use in Europe at a regional (country) level in practice.

2.5 Net Annual Increment (NAI) as the base for estimation of ecologically sustainable annual increment use on country level

Annual increment on an area entity of 1 ha is in fact the change in absolute biometrical values in vertical (height) and horizontal (diameter) directions presented through a function describing the spatial dynamic of these changes. As has been already emphasized, the dynamic of these changes (growth) depends on a number of variables with abiotic, biotic and anthropogenic backgrounds.

To avoid the necessity of taking into account the whole spectrum of these variables the result of their influence – the form of the stem – has been used as the only one and the main variable to describe forest stand productivity. Through applying ecological rules presented in abstract forms (please see Chapter 2.2.2 and Figures 3 to 8) the theoretical "point of balance" has been estimated. This step by step added "points of balance" (please see previous page) has been used to calculate the percentage of ecologically sustainable level of annual increment use from stands growing under significantly different site conditions. The dependence (and the function describing this dependence) between Net Annual Increment and percentage of its use is presented in Figure 9.

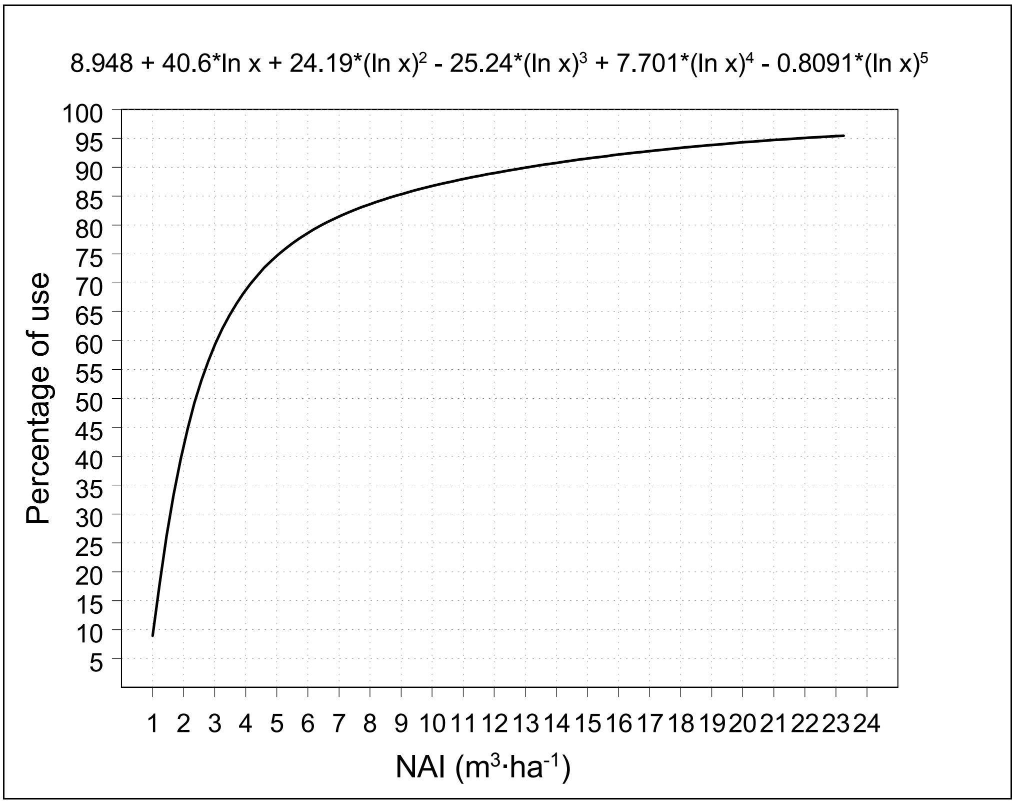

Figure 9: Dependence between Net Annual Increment and percentage of its use

The scale NAI in Figure 9 represents the values composed as results from different combinations of average age, site index, stand structure etc. In fact "average" forest stand is seen here as an abstract notion which is able to produce Y-amount of woody biomass by using of X-amount of available natural resources.

Very important for further practical use of the method developed in the project: we are able to move from the "real → abstract" notion Age (tree rings → horizontal growth → base of cylinder) to an "abstract → real" notion NAI (height / base of cylinder (diameter) – ratio → forest stand productivity → Net Annual Increment). The connecting link here is site conditions. NAI is actually the average annual increment from N-number of different aged forest stands growing under given site conditions. So, respecting this, Net Annual Increment of a particular country can be accepted as annual increment of an average stand representing this country (that is why the abscissa in Figure 9 is marked "NAI").

From such a point of view it makes it possible to extend the above explained abstract projections from local (stand) to regional (country) scale.

In this context three very important points have to be mentioned here:

- we operate strictly with the data provided by country [6] without having to analyze the age structure of that country's forests;
- the corresponding imaginary average stand site index is not known;
- and, the most important point, it is accepted that forest management has been carried out on an ecologically sustainable level.

The functional dependence presented in Figure 9 has been received through analysis and spatial interpretation of fundamental ecological rules [4, 5]. Although there are always some points to be improved (or adjusted), in general, theoretical aspects and practical results (please see Figure 3 and Figure 9) presented in the methodological part of this Report can be used for estimation (or evaluation) of sustainable level of renewable natural resources use.

In the following paragraphs, the above described functional dependence will be applied at country level for estimation of available wood resources in Europe. The maximal level of forest ecosystem exploitation will be calculated and different scenarios will be considered (based on the notion of ecological sustainability of forest ecosystems).

3. Results

3.1 Potential sustainable wood supply from European forests

The functional dependence presented in Figure 9 has been used for estimation of percentage of sustainable Net Annual Increment use. Values of NAI in cubic metres per hectare have been taken from MCPFE ("Forest Europe") Report 2007 [6] which was at the time of writing the most complete source of information concerning European forests. Table 1 provides results of calculation of Net Annual Increment in Mio m^3 and maximal potential annual wood supply from FAWS (129.132 Mio ha in total) of 25 EU Member States.

Table 1: Annual maximal potential wood supply from forests available for wood supply (FAWS) of 25 EU Member States (except Cyprus and Malta) *

Country	NAI in 2005, $m^3 \cdot ha^{-1}$	NAI use, %	FAWS, 1000 ha	NAI, Mio m^3	Wood supply, Mio m^3
Austria (2000)	9.4	85.8	3354	31.255	26.832
Belgium	7.9	83.4	667	5.289	4.409
Bulgaria	5.5	76.8	2561	14.120	10.845
Czech Republic	8.1	83.7	2518	20.500	17.167
Denmark	**13.4**	**90.1**	385	5.176	4.666
Estonia	5.3	76.0	2090	11.015	8.371
Finland	4.6	72.6	20004	92.860	67.425
France	6.9	81.2	14743	102.456	83.163
Germany	**11.1**	**88.0**	10984	122.000	107.316
Greece (1990)	1.3	20.8	3455.6	3.813	0.795
Hungary	7.7	83.0	1684	12.899	10.702
Ireland	8.7	84.8	656.3	5.707	4.839
Italy	4.3	70.8	8921.5	38.320	27.139
Latvia	5.8	77.9	2843.7	16.500	12.856
Lithuania	5.4	76.4	1835	9.888	7.555
Luxembourg	7.5	82.6	86.1	0.650	0.537
Netherlands	7.6	82.8	295	2.230	1.846
Poland	8.0	83.6	8417	67.595	56.479
Portugal (2000)	6.4	79.8	2009	12.900	10.298
Romania	7.5	82.6	4627.5	34.600	28.563
Slovakia	6.8	80.9	1751.2	11.980	9.694
Slovenia	6.3	79.5	1155	7.277	5.787
Spain (2000)	2.7	55.1	10479	28.589	15.758
Sweden	4.3	70.8	21235	91.355	64.700
UK	8.7	84.8	2375	20.700	17.550
TOTAL			**129131.9**	**769.67**	**605.29**

* Net Annual Increment in 2005 and NAI use for Denmark and Germany are marked bold where NAI use values exceed theoretical maximal sustainable percentage of 86.6 %. Corresponding years for Austria, Greece, Portugal and Spain are given in brackets. Data for Ireland have been interpolated from UK data.

While Net Annual Increment from 25 Member States makes 769.7 Mio m^3 in total, the theoretical maximal sustainable amount of wood potentially supplied from European forests (countries mentioned in Table 1) in 2005 could be 605.3 Mio m^3. Under existing site (climatic) conditions any amount of wood supplied above this number would lead to deterioration of ecological sustainability and the loss of potential productivity of European forests. And even this number is optimistic concerning future projections.

Concerning projections for the future, information about available wood resources should be structured from country to country at European level and from administrative region to administrative region at country level. In this report we operate at country level. It is possible and makes sense to compare the amount of wood supplied in each country in 2005 with the amount of wood which theoretically could be harvested in 2005 should forest management in the corresponding country be made on a sustainable basis. The difference will roughly mark the theoretical additional amount of wood which could potentially be supplied by European forests (please see Tab. 2).

Table 2: Theoretical additional amount of wood which could be supplied by European forests in corresponding year 2005

Country	Theoretical NAI use		Supplied in 2005		Additional yield	
	Mio m^3	%	Mio m^3	**%**	Mio m^3	**%**
Austria (2000)	26.832	85.8	18.797	60.1	8.035	25.7
Belgium	**4.409**	**83.4**	**4.475**	**84.6**	**-0.066**	**-1.2**
Bulgaria	10.845	76.8	5.768	40.8	5.077	36.0
Czech Republic	**17.167**	**83.74**	**17.190**	**83.85**	**-0.023**	**-0.1**
Denmark	4.666	90.1	1.837	35.5	2.829	54.7
Estonia	8.371	76.0	5.730	52.0	2.641	24.0
Finland	67.425	72.6	64.526	69.5	2.899	3.1
France	83.163	81.2	56.623	55.3	26.540	25.9
Germany	107.316	88.0	60.770	49.8	46.546	38.2
Greece (1990)	**0.795**	**20.8**	**2.979**	**78.1**	**-2.184**	**-57.3**
Hungary	10.702	83.0	7.167	55.6	3.535	27.4
Ireland	4.841	84.8	2.700	47.3	2.141	37.5
Italy	27.139	70.8	10.105	26.4	17.034	44.5
Latvia	12.856	77.9	11.290	68.4	1.566	9.5
Lithuania	7.555	76.4	7.238	73.2	0.317	3.2
Luxembourg	0.537	82.6	0.249	38.3	0.288	44.2
Netherlands	1.846	82.8	1.552	69.6	0.294	13.2
Poland	56.479	83.6	37.156	55.0	19.323	28.6
Portugal (2000)	**10.298**	**79.8**	**10.590**	**82.1**	**-0.292**	**-2.3**
Romania	28.563	82.6	15.900	46.0	12.663	36.6
Slovakia	9.694	80.9	8.962	74.8	0.732	6.1
Slovenia	5.787	79.5	3.203	44.0	2.584	35.5
Spain (2000)	**15.758**	**31.1**	**17.965**	**62.8**	**-2.207**	**-31.7**
Sweden	**64.700**	**70.8**	**78.127**	**85.5**	**-13.427**	**-14.7**
UK	17.550	84.8	9.900	47.8	7.650	37.0
TOTAL	**605.29**	**78.64**	**460.799**	**59.87**	**144.496**	**18.77**

On the basis of results presented in Table 1 and Table 2 it is possible to make some first conclusions concerning the additional amount of wood available in European forests (FAWS). The maximal sustainable amount of wood potentially available from European forests in 2005 was 605.3 Mio m^3 or 78.6 % of Net Annual Increment (769.7 Mio m^3 in 2005). In total 460.8 Mio m^3 were supplied, which makes 59.9 % of net annual increment in the corresponding year. It means that in 2005 it was theoretically possible to harvest an additional 144.5 Mio m^3 or 18.8 % of net annual increment of 769.7 Mio m^3 (key word here is "theoretically").

It has to be underlined here that the result achieved through application of the method described in this report (Chapter 2) almost precisely corresponds to the results achieved by Mr. Sebastian Hetsch (UNECE) in 2008 [7]. It was shown in his study "Potential Sustainable Wood Supply in Europe" that "the largest potential for additional wood supply in European countries is in the forests. Of the total of 233 million cbm, 34% is stemwood and 26% other aboveground woody biomass". His report mentioned 60 % (34 + 26) from a total estimated 233 Mio m^3 makes additional wood supply from European forests of 139.8 Mio m^3 per year (233 × 0.6: please compare with the result of 144.5 Mio m^3 presented in this report). This fact can be seen as evidence of reliability of the method developed during the work on this project. There is other evidence of reliability of the method proposed here. The amount of forest wood supply projected in this report corresponds exactly (difference 0.1 %) to the amount of forest wood in fact supplied by the Czech Republic – the country with relative homogeneous site conditions and with one of the highest levels of forest management practice (please see Table 2).

An advantage of this method is the possibility to evaluate at country level the sustainability of forest wood resource exploitation. But the biggest advantage is that it makes it possible to make operational projections of potential forest wood availability in the near, middle or far future with respect to sustainability of forest management practice, which has its particularities in each country or region.

An example: According to results presented in Table 2, forests in Greece and Spain are extremely overused. Portugal will also not be able to increase wood supply. At the same time, projection for Italy shows the second highest potential after Denmark for additional yield from forests available for wood supply (please see the last column of Table 2). The background for differences between previously made conclusions for South Europe [8] and achieved results for Italy in this Report will be understandable after the following explanation:

1. The method works on the assumption that NAI use cannot be equal to 100 % and by decreasing site productivity, percentage of NAI use will also decrease;
2. All projections are made on assumptions of sustainable forest management practice (key point here: normalized age structure);
3. According to the study by S. Hetsch "Potential Sustainable Wood Supply in Europe", Italy "has more forest in young age classes than old, and thus less wood available for final harvest" [7]. According to Table 13 on page 20 of the source, Italy has more than 30 % of its stands in age between 40-60 years and less than 10 % of its stands in age between 60-100 years. Such an age structure leads to over-estimation of NAI;
4. Overestimated NAI leads to over estimation of percentage of sustainable use of forest wood resources;
5. Overestimated percentage of NAI use will lead to over-exploitation of that country's forests (and ecosystem in general).

3.2 Changes of Net Annual Increment with time and resulted changes in amount of forest wood theoretically available for supply

In the previous chapter the case with overestimation of potential wood supply from Italy was presented. Such over (or under) estimations can come to light in any country and the scale of the error will depend on site indexes and their distribution, forest stand age class distribution, and forest management practices. If we assume that forest management practices have not changed drastically during the last 20-30 years then we have nearly the same sites index values in our corresponding period (the year 2005). In this case almost only the change in age class distribution will lead to a significant change in value of NAI and in estimation of potential wood supply by that country's forests.

Results presented in Table 3 make these cases more clear.

Table 3: Changes of Net Annual Increment with time and resulted changes in amount of forest wood theoretically available for supply

Country	NAI in $m^3 \cdot ha^{-1}$		Change in % (2005 to 1990)	NAI use in Mio m^3		Change in % (2005 to 1990)
	1990	2005		1990	2005	
Czech Republic	6.6	8.1	22.7	9.057	10.819	19.5
Bulgaria	4.8	5.5	14.6	13.360	17.080	27.8
Denmark	13.2	13.4	1.5	4.573	4.651	1.7
Estonia	5.9	5.3	-10.2	9.651	8.418	-12.8
Finland	3.5	4.6	31.4	45.244	66.814	47.7
France	6	6.9	15.0	69.524	82.571	18.8
Hungary	7.2	7.7	6.9	9.929	10.758	8.4
Italy	3.5	4.3	22.9	20.179	27.171	34.6
Luxembourg	7.6	7.5	-1.3	0.542	0.533	-1.6
Netherlands	7.8	7.6	-2.6	1.914	1.856	-3.0
Slovakia	5.7	6.8	19.3	7.741	9.635	24.5
Slovenia	4.5	6.3	40.0	3.744	5.787	54.6
Sweden	4.2	4.3	2.4	62.584	64.669	3.3
UK	8.4	8.7	3.6	16.814	17.518	4.2
TOTAL	**4.7**	**5.4**	**14.9**	**274.855**	**328.279**	**19.4**

As we can see from Table 3 both NAI itself and NAI use dependent on annual increment have changed significantly during the 15 year period from 1990 to 2005. The reason for differences in percentages is explainable through non-linear dependence between NAI and percentage of NAI use (please see Figure 9).

According to results presented in Table 3, the biggest changes occurred in Slovenia (40.0 and 54.6 %), followed by Finland (31.4 and 47.7 %), and Italy (22.9 and 34.6 %). This is when results are directly compared. Quite different results will be achieved if the increase in NAI values relative to 1 $m^3 \cdot ha^{-1}$ are compared.

The algorithm of calculations and results corresponding to these calculations are presented below. As can be seen below, the biggest changes in fact occurred not in Slovenia but in Italy.

Calculations:

Slovenia

$$\frac{54.6-40.0}{40.0}\times 100 = 36.5$$ 36.5 ÷ (6.3 – 4.5) = 36.5 ÷ 1.8 = 20.3 %

Italy

$$\frac{34.6-22.9}{22.9}\times 100 = 51.1$$ 51.1 ÷ (4.3 – 3.5) = 51.1 ÷ 0.8 = 63.9 %

Finland

$$\frac{47.7-31.4}{31.4}\times 100 = 51.9$$ 51.9 ÷ (4.6 – 3.5) = 51.9 ÷ 1.1 = 47.2 %

Average (14 presented in Table 3 countries)

$$\frac{19.4-14.9}{14.9}\times 100 = 30.2$$ 30.2 ÷ (5.4 – 4.7) = 30.2 ÷ 0.7 = 43.1 %

These results can be explained and interpreted as following:

- 1 $m^3 \cdot ha^{-1}$ increase in NAI will lead to different increases in NAI use intensity;
- an increase in NAI does not automatically mean an increase in potential site productivity: if increase in NAI results exclusively through the change in age structure of the stands then we risk to over-use given sites (countries' forest ecosystems) by up to the above calculated percentage;
- by decreasing site productivity the risk to over-use forest ecosystems increases.

As has been already mentioned the main problem in estimation of potential wood supply from European forests is that we do not know the distribution of site indexes and the age structure of the stands. We are not familiar with forest management practices specific for each country. That is why (also taking into account the above numbers) it will be very dangerous to assume that the theoretical 144.5 Mio m^3 of additional wood supply (please see Table 2) could be immediately available for use. Optimisation of forest resource use and increase of forest site productivity are long term processes. But these two elements are “the must” of sustainable forest wood supply.

With respect to the above, a moderate step-by-step increase of wood supply from European forests will be proposed in this Report.

3.3 Potential sustainable forest wood supply from European forests in near, middle and far future

There is a long series of special time scaled technological operations in forestry. One of the main aims of these operations is to get the most valuable forest resource – high quality wood – at the end of the chain of planned operations. All measurements have to be made on scientific basics and approved in practice if we want to achieve the highest level of forest wood resources use and, at the same time, to keep ecological sustainability of forest ecosystems at an appropriate level. Any drastic immediate interventions (like a significant increase in wood supply) in measurements carefully planned by National Forest Inventories can lead in the future to backward trends in forest wood supply as well as decreasing the ecological sustainability of forest ecosystems. This is why a timely scaled, moderate step-by-step increase of wood supply from European forests in the near, middle and far future is proposed in this Report (Table 4).

Table 4: Potential forest wood availability from European forests in the near, middle, and far future (please read further explanation in text)

Country	Annual wood supply by coefficient, in Mio m^3					
	1.0	**0.931**	**0.866**	**0.806**	0.763 (2005)	**0.750**
Austria	26.832	24.970	23.237	21.624	**18.797**	20.124
Belgium	4.409	4.103	3.818	3.553	**4.475**	3.307
Bulgaria	10.845	10.092	9.392	8.740	**5.768**	8.134
Czech Republic	17.167	15.976	14.867	13.835	**17.190**	12.875
Denmark	4.666	4.342	4.041	3.760	**1.837**	3.499
Estonia	8.371	7.790	7.250	6.746	**5.730**	6.278
Finland	67.425	62.746	58.391	54.339	**64.526**	50.569
France	83.163	77.392	72.021	67.024	**56.623**	62.372
Germany	107.316	99.869	92.939	86.489	**60.770**	80.487
Greece	0.795	0.740	0.688	0.641	**2.979**	0.596
Hungary	10.702	9.959	9.268	8.625	**7.167**	8.027
Ireland	4.841	4.505	4.192	3.901	**2.700**	3.631
Italy	27.139	25.256	23.503	21.872	**10.105**	20.355
Latvia	12.856	11.964	11.134	10.361	**11.290**	9.642
Lithuania	7.555	7.031	6.543	6.089	**7.238**	5.666
Luxembourg	0.537	0.499	0.465	0.432	**0.249**	0.402
Netherlands	1.846	1.718	1.598	1.487	**1.552**	1.384
Poland	56.479	52.560	48.912	45.518	**37.156**	42.359
Portugal	10.298	9.583	8.918	8.299	**10.590**	7.723
Romania	28.563	26.581	24.736	23.020	**15.900**	21.422
Slovakia	9.694	9.021	8.395	7.812	**8.962**	7.270
Slovenia	5.787	5.386	5.012	4.664	**3.203**	4.340
Spain	15.758	14.665	13.647	12.700	**17.965**	11.819
Sweden	64.700	60.210	56.032	52.144	**78.127**	48.525
UK	17.550	16.332	15.199	14.144	**9.900**	13.162
TOTAL	**605.29**	**563.290**	**524.200**	**487.823**	**460.799**	**453.971**

In Table 4 proposed calculation of potential sustainable wood supply from European forests (FAWS) in the near, middle and far future is based on coefficients principle.

The coefficients proposed in the methodological part of this Report (page 26) have been used for estimation of the proposed step-by-step increase of annual wood supply. The one additional coefficient of 0.806 (0.931^3) has been used “to smooth” the “first step” in forest wood supply increase.

The time frames are proposed to scale as following:

- near future – up to 2020;
- middle future – 2020-2050;
- far future – 2050 and thereafter.

According to statistical information presented by MCPFE [6] 460.8 Mio m^3 (average coefficient 0.763 of theoretical NAI use, please see Table 4) of wood was supplied in 2005 from forests available for wood supply of 25 Member States. At the time of writing, statistical data for 2010 were not available, but the value of 480 ± 20 Mio m^3 (coefficient 0.806 = 487.823 Mio m^3) can be seen as a reliable and easily achievable amount of wood for supply annually between 2005 and 2010.

With respect to the above proposed time scale and corresponding coefficients the following amount of wood can be seen as sustainable wood supply by European forests:

- in near future – 520 ± 20 Mio m^3 (coefficient 0.866)
- in middle future – 560 ± 20 Mio m^3 (coefficient 0.931)
- in far future – 600 ± 20 Mio m^3 (coefficient 1.0)

As already mentioned, all of the above made projections are indicative but are relatively easily achievable up to the projected value for the middle future of 560 ± 20 Mio m^3. To move ahead (up to 600 Mio m^3 and above) strictly planned measurements at European and Member State levels have to be made. A very important point to be mentioned here is that all (or almost all) the decisions have to be made with respect to and in accordance with National Forest Inventories. To this conclusion we will come after simple analysis of data presented in Table 4. Some countries, for example Belgium, Czech Republic, Slovakia, have already achieved their potential for amount of wood supply. Some countries, like Greece, significantly overuse their forests and some countries, like Germany, underuse their potential. So, very different but coordinated solutions have to be made at European, country and regional level.

It can be assumed on the base of the above presented results that it is feasible to achieve approximately 30 % increase of annual wood supply from European forests in around 40-50 years time frame. Under this scenario ecological sustainability of forest ecosystems throughout Europe can be successfully maintained.

3.4 Available forest wood resources in Europe for energy supply

…The way from energy conserved in biomass back to primary energy should be as long as possible.

Any kind of “mass” (biomass or other kind of “mass”) is in possession of its potential energy. From this point of view all at the moment theoretically available 605.3 Mio m^3 wood from European forests (FAWS) could be used for energy supply purposes. The question is only: would it be ecologically and economically sustainable? Or, expressed in other way: which is the number or where are the frames of sustainable forest wood resources use for energy supply purpose?

There are a number of projects, reports and presentations which have investigated the ability of European forests to satisfy increasing demand in wood as the source of renewable energy. Among them are:

Biomass Energy Europe (BEE) – Illustration Case for Europe http://www.eu-bee.com/default.asp?SivuID=24158

EUwood – Real potential for changes in growth and use of EU forests http://ec.europa.eu/energy/renewables/studies/bioenergy_en.htm

Potential Sustainable Wood Supply in Europe http://timber.unece.org/fileadmin/DAM/publications/Dp-52.pdf

The legend of the woody biomass reserve in Europe http://www.unece.org/timber/workshops/2007/wmw/presentations/biomass_resources_Mantau.pdf

It has to be mentioned here the presentation “Sustainable use of wood for Products and Energy: Conflict or Opportunity?” made by Dr. Chris Van Riet on conference “Les za izdelke ali kurjavo” (“Wood products or firewood”) held in Ljubljana on September 7, 2004 [http://www.europanels.org/main_tc.html]. The topic and information given in this presentation correspond almost precisely to the idea expressed in two lines on the top of this page.

Giving first priority to ecological rules, this Report proposes solutions aiming to maintain the ecological sustainability of forest ecosystems.

The results presented below are based on the assumption that the spatial structure of a stand corresponds to given site conditions, and that the trees growing in a particular stand, given essential resources to grow (water, light, nutritive elements), will respond to existing growing conditions. From a human (as a user) point of view this results in more (material use) or less (energy purpose use) valuable stems.

3.5 Reasonable amount of European forests' wood resources which can be used for energy supply purpose

In the methodological part of this project we came to the conclusion that 86.6 % (cos 30 = 0.866025404) is the "level of balance" for forest ecosystem use. If we start to calculate step by step from Site Conditions level (as shown in Figure 2 b) and go up to Economy level (please see Figure 2 a) then we will come to the following figures:

$1 \rightarrow 0.866025404 \rightarrow 0.866025404^{2} \rightarrow 0.866025404^{3}$

or corresponding percentages:

100 → 86.6 → 75.0 → 65.0 %

This is the theory of the near to ideal situation. As we have to come down to practice and be able to balance near to real situation, three scenarios (or projections) will be proposed here – optimistic projection, realistic projection, and pessimistic projection – for both material oriented and energy oriented use of forest wood resources.

The connections of projections are following.

Realistic projection for material oriented use is combined with realistic projection for energy oriented use. Optimistic projection for material oriented use will be combined with pessimistic projection for energy oriented use and pessimistic projection for material oriented use will be combined with optimistic projection for energy oriented use.

By above mentioned combinations the algorithms of calculations will be applied in such a way:

Optimistic material use O_m:	$O_m = x \cdot y$
Pessimistic energy use P_e :	$P_e = x \cdot (1 - y)$
Realistic material use R_m:	$R_m = x \cdot y^2$
Realistic energy use R_e:	$R_e = x \cdot (1 - y^2)$
Pessimistic material use P_m:	$P_m = x \cdot y^3$
Optimistic energy use O_e:	$O_e = x \cdot (1 - y^3)$

Where: x – is Net Annual Increment use in Mio m^3
(for example for Austria x = 26.832 Mio m^3);

y – is Net Annual Increment use in % divided by 100
(for Austria y = 85.8 / 100 = 0.858)

So, as example, for Austria we will get the following numbers:

$O_m = x \cdot y = 26.832 \cdot 0.858 = 23.034$ Mio m^3
$P_e = x \cdot (1 - y) = 26.832 \cdot (1 - 0.858) = 3.797$ Mio m^3
$R_m = x \cdot y^2 = 26.832 \cdot 0.858^2 = 19.775$ Mio m^3
$R_e = x \cdot (1 - y^2) = 26.832 \cdot (1 - 0.858^2) = 7.057$ Mio m^3
$P_m = x \cdot y^3 = 26.832 \cdot 0.858^3 = 16.976$ Mio m^3
$O_e = x \cdot (1 - y^3) = 26.832 \cdot (1 - 0.858^3) = 9.856$ Mio m^3

The results of calculations for each Member State (except Cyprus and Malta) and EU-25 in total are presented in Tables 5 and 6 (please note that the numbers are rounded: in example above 0.858 is rounded from 0.858478152).

Table 5: Material oriented and energy oriented wood resources use – realistic projection

Country	NAI use		Material oriented use, Mio m^3		Energy oriented use, Mio m^3	
	Mio m^3	%	Optimistic projection	Realistic projection	Realistic projection	Pessimistic projection
Austria	26.832	85.8	23.034	19.775	7.057	3.797
Belgium	4.409	83.4	3.676	3.064	1.345	0.733
Bulgaria	10.845	76.8	8.330	6.398	4.447	2.515
Czech Republic	17.167	83.7	14.376	12.039	5.128	2.791
Denmark	4.666	90.1	4.206	3.792	0.874	0.460
Estonia	8.371	76.0	6.362	4.835	3.536	2.009
Finland	67.425	72.6	48.956	35.547	31.878	18.468
France	83.163	81.2	67.503	54.792	28.371	15.660
Germany	107.32	88.0	94.400	83.038	24.278	12.916
Greece	0.795	20.8	0.166	0.035	0.760	0.629
Hungary	10.702	83.0	8.879	7.367	3.335	1.823
Ireland	4.841	84.8	4.104	3.480	1.361	0.737
Italy	27.139	70.8	19.221	13.613	13.527	7.918
Latvia	12.856	77.9	10.017	7.805	5.051	2.839
Lithuania	7.555	76.4	5.773	4.411	3.144	1.782
Luxembourg	0.537	82.6	0.443	0.366	0.171	0.094
Netherlands	1.846	82.8	1.527	1.264	0.581	0.318
Poland	56.479	83.6	47.191	39.431	17.048	9.288
Portugal	10.298	79.8	8.220	6.562	3.736	2.077
Romania	28.563	82.6	23.580	19.465	9.098	4.984
Slovakia	9.694	80.9	7.844	6.347	3.347	1.850
Slovenia	5.787	79.5	4.603	3.661	2.126	1.184
Spain	15.758	31.1	8.686	4.787	10.971	7.072
Sweden	64.700	70.8	45.823	32.453	32.247	18.878
UK	17.550	84.8	14.879	12.615	4.935	2.671
TOTAL	**605.3**	**78.6**	**481.800**	**386.941**	**218.354**	**123.495**
Percentage	100		79.6	**63.9**	**36.1**	20.4

Table 6 also presents a theoretical "very optimistic" projection as the sum of Optimistic Material Use and Optimistic Energy Use projections. As can be seen from Table 6 in this case the total amount of wood supplied by European forests (774.017 Mio m^3 – calculated number) would correspond to 100 % use of Net Annual Increment (769.764 Mio m^3 – according to the data provided by National Forest Inventories for the year 2005 [6]).

Should such a theoretical projection actually happen then European forests will be overused by 27.9 % (please see the last column of Table 6).

Table 6: Material oriented and energy oriented wood resources use – optimistic projection and connected with it forest ecosystem overuse (please see also Table 5)

Country	NAI use		Material use	Energy use	The sum of optimistic projections, Mio m^3	Forest ecosystem (over)use, %
	Mio m^3	%	Pessimistic projection	Optimistic projection		
Austria	26.832	85.8	16.976	9.856	32.890	122.6
Belgium	4.409	83.4	2.554	1.855	5.530	125.4
Bulgaria	10.845	76.8	4.914	5.931	14.261	131.5
Czech Republic	17.167	83.7	10.082	7.086	21.462	125.0
Denmark	4.666	90.1	3.418	1.248	5.454	116.9
Estonia	8.371	76.0	3.674	4.697	11.059	132.1
Finland	67.425	72.6	25.810	41.615	90.571	134.3
France	83.163	81.2	44.475	38.689	106.192	127.7
Germany	107.32	88.0	73.044	34.273	128.672	119.9
Greece	0.795	20.8	0.007	0.788	0.953	119.9
Hungary	10.702	83.0	6.112	4.590	13.469	125.9
Ireland	4.841	84.8	2.950	1.891	5.995	123.8
Italy	27.139	70.8	9.641	17.498	36.719	135.3
Latvia	12.856	77.9	6.082	6.775	16.792	130.6
Lithuania	7.555	76.4	3.370	4.185	9.958	131.8
Luxembourg	0.537	82.6	0.302	0.235	0.678	126.3
Netherlands	1.846	82.8	1.046	0.799	2.327	126.1
Poland	56.479	83.6	32.947	23.533	70.724	125.2
Portugal	10.298	79.8	5.238	5.059	13.280	129.0
Romania	28.563	82.6	16.069	12.494	36.073	126.3
Slovakia	9.694	80.9	5.136	4.558	12.402	127.9
Slovenia	5.787	79.5	2.912	2.876	7.479	129.2
Spain	15.758	31.1	2.639	13.119	21.805	138.4
Sweden	64.700	70.8	22.984	41.716	87.539	135.3
UK	17.550	84.8	10.695	6.855	21.734	123.8
TOTAL	**605.3**	**78.6**	**313.077**	**292.217**	**774.017**	**127.9**
Percentage	100		51.7	48.3	127.9	

This percentage is calculated as the follows:

$$\frac{774.017}{605.3} \times 100 = 127.9\ \%$$ (Please see the row TOTAL in Table 6)

Through dividing percentage of overuse by percentage of NAI use we will estimate each country's positioning (or coefficient) on its future potential in increasing forest wood resources supply. The results are presented in Table 7, where a lower coefficient value means higher potential in wood supply. The five countries with the highest and five countries with the lowest potentials in wood supply increase are marked bold.

Table 7: Countries' positioning on its future potential in increasing of forest wood resources supply

Country	NAI use		Overuse, % (100+X)	Difference to sustainable use in 2005, Mio m^3	Relation of Overuse to NAI use (%)
	Mio m^3	%			
1	2	3	4	5	6
Denmark	4.666	90.1	116.9	0.788	1.297
Germany	107.316	88.0	119.9	21.356	1.363
Austria	26.832	85.8	122.6	6.058	1.428
Ireland	4.841	84.8	123.8	1.154	1.461
UK	17.550	84.8	123.8	4.184	1.461
Czech Republic	17.167	83.7	125.0	4.295	1.493
Poland	56.479	83.6	125.2	14.245	1.499
Belgium	4.409	83.4	125.4	1.121	1.505
Hungary	10.702	83.0	125.9	2.767	1.517
Netherlands	1.846	82.8	126.1	0.481	1.523
Luxembourg	0.537	82.6	126.3	0.141	1.530
Romania	28.563	82.6	126.3	7.510	1.530
France	83.163	81.2	127.7	23.029	1.573
Slovakia	9.694	80.9	127.9	2.708	1.581
Portugal	10.298	79.8	129.0	2.982	1.615
Slovenia	5.787	79.5	129.2	1.691	1.625
EU25	**605.29**	**78.6**	**127.9**	**168.722**	**1.626**
Latvia	12.856	77.9	130.6	3.936	1.676
Bulgaria	10.845	76.8	131.5	3.416	1.712
Lithuania	7.555	76.4	131.8	2.403	1.725
Estonia	8.371	76.0	132.1	2.688	1.738
Finland	67.425	72.6	134.3	23.146	1.850
Italy	27.139	70.8	135.3	9.580	1.910
Sweden	64.700	70.8	135.3	22.839	1.910
Spain	15.758	55.1	138.4	6.047	2.510
Greece	0.795	20.8	119.9	0.158	5.754

As has already been mentioned in the methodological part of this Report we deal with continuously changing growing conditions. It will be also shown in the next Chapter that we also deal with changing numbers provided by the countries.

In such a situation the most appropriate way to find a solution and to make future projections is to operate with relative values (percentages), rather than with annually changing absolute figures.

For this reason the above projected volumes of material and energy uses of forest wood resources for realistic and optimistic projections will be presented in percentages (please see Tables 8 and 9).

Table 8: Percentages of material and energy uses of forest wood resources by realistic projection

Country	Annual yield, Mio m^3	Material use, Mio m^3	Energy use, Mio m^3	Material use, %	Energy use, %
1	2	3	4	5	6
Denmark	4.666	3.792	0.874	81.3	18.7
Germany	107.316	83.038	24.278	77.4	22.6
Austria	26.832	19.775	7.057	73.7	26.3
Ireland	4.841	3.480	1.361	71.9	28.1
UK	17.550	12.615	4.935	71.9	28.1
Czech Republic	17.167	12.039	5.128	70.1	29.9
Poland	56.479	39.431	17.048	69.8	30.2
Belgium	4.409	3.064	1.345	69.5	30.5
Hungary	10.702	7.367	3.335	68.8	31.2
Netherlands	1.846	1.264	0.581	68.5	31.5
Luxembourg	0.537	0.366	0.171	68.1	31.9
Romania	28.563	19.465	9.098	68.1	31.9
France	83.163	54.792	28.371	65.9	34.1
Slovakia	9.694	6.347	3.347	65.5	34.5
EU25	**605.29**	**386.941**	**218.354**	**63.9**	**36.1**
Portugal	10.298	6.562	3.736	63.7	36.3
Slovenia	5.787	3.661	2.126	63.3	36.7
Latvia	12.856	7.805	5.051	60.7	39.3
Bulgaria	10.845	6.398	4.447	59.0	41.0
Lithuania	7.555	4.411	3.144	58.4	41.6
Estonia	8.371	4.835	3.536	57.8	42.2
Finland	67.425	35.547	31.878	52.7	47.3
Italy	27.139	13.613	13.527	50.2	49.8
Sweden	64.700	32.453	32.247	50.2	49.8
Spain	15.758	4.787	10.971	30.4	69.6
Greece	0.795	0.035	0.760	4.3	95.7

Table 9: Percentages of material and energy uses of forest wood resources by optimistic projection

Country	Annual yield, Mio m^3	Material use, Mio m^3	Energy use, Mio m^3	Material use, %	Energy use, %
1	2	3	4	5	6
Denmark	5.454	4.206	1.248	77.1	22.9
Germany	128.672	94.400	34.273	73.4	26.6
Austria	32.890	23.034	9.856	70.0	30.0
UK	21.734	14.879	6.855	68.5	31.5
Ireland	5.995	4.104	1.891	68.5	31.5
Czech Republic	21.462	14.376	7.086	67.0	33.0
Poland	70.724	47.191	23.533	66.7	33.3
Belgium	5.530	3.676	1.855	66.5	33.5
Hungary	13.469	8.879	4.590	65.9	34.1
Netherlands	2.327	1.527	0.799	65.6	34.4
Luxembourg	0.678	0.443	0.235	65.4	34.6
Romania	36.073	23.580	12.494	65.4	34.6
France	106.192	67.503	38.689	63.6	36.4
Slovakia	12.402	7.844	4.558	63.2	36.8
EU25	**774.017**	**481.800**	**292.217**	**62.2**	**37.8**
Portugal	13.280	8.220	5.059	61.9	38.1
Slovenia	7.479	4.603	2.876	61.5	38.5
Latvia	16.792	10.017	6.775	59.7	40.3
Bulgaria	14.261	8.330	5.931	58.4	41.6
Lithuania	9.958	5.773	4.185	58.0	42.0
Estonia	11.059	6.362	4.697	57.5	42.5
Finland	90.571	48.956	41.615	54.1	45.9
Italy	36.719	19.221	17.498	52.3	47.7
Sweden	87.539	45.823	41.716	52.3	47.7
Spain	21.805	8.686	13.119	39.8	60.2
Greece	0.953	0.166	0.788	17.4	82.6

In Tables 8 and 9 the countries presented are positioned according to descending percentages of material use.

Now, after analysis of the above presented information, we are able to see a recognisable trend:

- at the beginning of this Chapter, theoretical relationships between percentages of material use and energy use of forest wood resources from FAWS were proposed: from 65 % (material use) to 35 % (energy use, please see page 42);
- the realistic projection presented in Table 8 gave us another relation: 63.9 % (material use) to 36.1 % (energy use);
- the optimistic projection for energy use purpose gave the following relation: 62.2 % (material use) to 37.8 % (energy use, please see Table 9).

When we apply the percentages presented in Table 9 to the values of sustainable wood supply from European forests calculated for corresponding year 2005 then we will obtain the amounts of wood for material and energy use as presented in Table 10 (countries are positioned according to descending amount of wood for energy use purpose).

Table 10: Proposed percentages and corresponding volumes for material use and energy use purposes by theoretical sustainable supply of forest wood resources in Europe

Country	Annual yield, Mio m^3	Material use, %	Energy use, %	Material use, Mio m^3	Energy use, Mio m^3
1	2	3	4	5	6
EU25	**605.29**	**62.2**	**37.8**	**376.776**	**228.519**
Finland	67.425	54.1	45.9	36.445	30.980
Sweden	64.700	52.3	47.7	33.868	30.833
France	83.163	63.6	36.4	52.865	30.299
Germany	107.316	73.4	26.6	78.732	28.584
Poland	56.479	66.7	33.3	37.686	18.793
Italy	27.139	52.3	47.7	14.206	12.933
Romania	28.563	65.4	34.6	18.670	9.893
Spain	15.758	39.8	60.2	6.277	9.481
Austria	26.832	70.0	30.0	18.791	8.040
Czech Republic	17.167	67.0	33.0	11.499	5.668
UK	17.550	68.5	31.5	12.015	5.535
Latvia	12.856	59.7	40.3	7.669	5.187
Bulgaria	10.845	58.4	41.6	6.335	4.511
Portugal	10.298	61.9	38.1	6.374	3.923
Hungary	10.702	65.9	34.1	7.055	3.647
Slovakia	9.694	63.2	36.8	6.131	3.563
Estonia	8.371	57.5	42.5	4.816	3.555
Lithuania	7.555	58.0	42.0	4.380	3.175
Slovenia	5.787	61.5	38.5	3.562	2.225
Ireland	4.841	68.5	31.5	3.314	1.527
Belgium	4.409	66.5	33.5	2.930	1.479
Denmark	4.666	77.1	22.9	3.598	1.068
Greece	0.795	17.4	82.6	0.138	0.657
Netherlands	1.846	65.6	34.4	1.212	0.634
Luxembourg	0.537	65.4	34.6	0.351	0.186

Table 10 presents the suggested amount of wood which can be directly supplied by European forests (FAWS) for material and energy use purposes in the far future (around 2050). The five countries with the highest and those with the lowest potentials in wood supply (absolute values) for energy purpose are marked in bold.

These absolute values are very uncertain, since they are strongly influenced not only by changing site conditions and corresponding changes in the ecological productivity of forest stands, but also by changing technological development, sociological constraints, and political reasons. That is why not absolute but relative values (percentages) are proposed below.

As can be seen from Table 9 the value 62 ± 10 % of wood for material use purpose will overlap almost all the data presented in column 5 except the figures from Denmark and Germany (please see Chapter 3.6 for explanation) at the top and those from Spain and Greece at the bottom of Table 9.

This percentage comes from a rounded average value for Europe (62.2 %, Table 9) and the difference between the two levels of ecosystem use presented on page 42:

$$0.866025404^{2} - 0.866025404^{3} = 0.75 - 0.65 = 0.1$$

$$0.1 \times 100 = 10\ \%$$

It means that for most countries (21 of the 25 presented in Table 9) around 28 to 48 % of wood from forests available for wood supply can be directed to energy use purpose.

For the European average the value of 62 ± 5 % can be used. It means that approximately 33 to 43 % (average 38 %) of wood from forests available for wood supply (FAWS) can be removed directly for energy use purpose. But it should be again emphasized here that the main purpose of forestry as a branch of economy is to supply high quality wood, which means that the aim of increasing material use of wood has to be permanently strengthened.

3.6 Analysis of mismatches and errors

At the end of the project it became possible to verify some projections made for the time before near future with the real numbers presented by Eurostat news release (**International Year of Forests 2011: Forests cover around 40% of the EU27 land area. Half the EU27 consumption of renewable energy comes from wood** in http://europa.eu/rapid/pressReleasesAction.do?reference=STAT/11/85&format=HTML&aged=0&language=EN&guiLanguage=en), and taken from data provided by countries for Forest Europe in 2011 [10] (**State of Europe's Forests 2011 Report** http://www.foresteurope.org/pBl7xY4UEJFW9S_TdLVYDCFspY39Ec720-U9or6XP.ips).

Projected amounts of wood from European forests available for wood supply (FAWS) are compared with figures actually supplied by the countries and presented in Table 11. The numbers in the last three columns presents official data taken from the State of Europe's Forests Reports 2007 and 2011.

Table 11: Projected (bold font) and in fact supplied wood from European forests available for wood supply (please see also explanation in text)

Country	In fact supplied and projected by coefficient annual wood supply, in Mio m^3					
	0.931 projected	**0.866** projected	**0.806** projected	0.802 (2010/11)	0.840 (2005/11)	0.774 (2005/07)
Austria	24.970	23.237	21.624	23.511 (24)	23.511	**23.511**
Belgium	4.103	3.818	3.553	3.852 (4)	4.475	4.475
Bulgaria	10.092	9.392	8.740	7.781 (8)	5.768	5.768
Czech Republic	15.976	14.867	13.835	17.940 (18)	18.273	17.190
Denmark	4.342	4.041	3.760	2.371 (2)	2.307	1.837
Estonia	7.790	7.250	6.746	5.714 (6)	6.662	5.730
Finland	62.746	58.391	54.339	59.447 (59)	64.356	64.526
France	77.392	72.021	67.024	64.316 (64)	59.262	56.623
Germany	99.869	92.939	86.489	59.610 (60)	75.336	60.770
Greece	0.740	0.688	0.641	**1.842** (2)	1.842	1.842
Hungary	9.959	9.268	8.625	6.899 (7)	6.992	7.167
Ireland	4.505	4.192	3.901	2.826 (3)	2.915	**2.915**
Italy	25.256	23.503	21.872	12.755 (13)	13.298	10.105
Latvia	11.964	11.134	10.361	12.421 (12)	16.359	11.29
Lithuania	7.031	6.543	6.089	8.600 (9)	9.040	7.238
Luxembourg	0.499	0.465	0.432	**0.249** (0)	**0.249**	0.249
Netherlands	1.718	1.598	1.487	1.552 (2)	1.552	1.552
Poland	52.560	48.912	45.518	40.693 (41)	38.316	37.156
Portugal	9.583	8.918	8.299	**14.229** (14)	14.229	13.286
Romania	26.581	24.736	23.020	17.232 (17)	16.473	15.9
Slovakia	9.021	8.395	7.812	10.418 (10)	9.146	8.962
Slovenia	5.386	5.012	4.664	3.401 (3)	3.232	3.203
Spain	14.665	13.647	12.700	16.577 (17)	17.369	19.093
Sweden	60.210	56.032	52.144	80.900 (81)	86.400	78.127
UK	16.332	15.199	14.144	10.500 (11)	10.560	9.900
TOTAL	**563.290**	**524.200**	**487.823**	485.636 (484)	507.922	468.415

The coefficients in Table 11 present the relation of projected (**bold font**) and actually supplied figures for theoretically available wood resources in European forests (605.3 Mio m^3 = 1, please see also Table 4 on page 38). Differences between the data presented in Table 4 and Table 11 are due to the fact that in Table 4 for some countries we have used fellings data corresponding to the year for which NAI data was available (please see Table 1 on page 31).

Coefficient 0.931 corresponds to a middle future projection of annual wood supply of 560 ± 20 Mio m^3 for a 30 year time frame (2020-2050, p. 39).

Coefficient 0.866 corresponds to a near future projection of annual wood supply of 520 ± 20 Mio m^3 for a 10 year time frame (2010-2020).

Coefficient 0.806 has been proposed for the time period 2005-2010 with an annual wood supply of 480 ± 20 Mio m^3 (corresponding value 487.8 Mio m^3).

Coefficient 0.802 is the overall coefficient for wood supplied in 2010 according to data provided in the "State of Europe's Forests Report 2011" (numbers in brackets correspond to data provided by Eurostat news release, please see Table 11 on page 50).

Coefficient 0.840 is the overall coefficient for wood supplied in 2005 according to data provided in the "State of Europe's Forests Report 2011" and the coefficient 0.774 is the overall coefficient for wood supplied in 2005 according to data provided in the "State of Europe's Forests Report 2007". For some countries **bold** marked numbers mean that for this year there were no data available from the above stated Report. In these cases, **bold** marked numbers are taken from another Report (for example: Ireland has not provided data for fellings in State of Europe's Forests Report 2007 – data taken from Report 2011; and Luxembourg has not provided data for fellings in State of Europe's Forests Report 2011 – data taken from Report 2007).

If we calculate an average from two years (2005 and 2010 – the first and the last years of 2005-2010 period) using values taken from the State of Europe's Forests Reports of 2011 and 2007 then we will arrive at the following numbers:

1. (485.636 + 507.922)/ 2 = 496.779 ≈ 496.8 Mio m^3
2. (485.636 + 468.415)/ 2 = 477.026 ≈ 477.0 Mio m^3

Both of these numbers are positioned in frames projected in this Report for the time period 2005-2010 with an annual wood supply from European forests of 480 ± 20 Mio m^3 (corresponding value 487.8 Mio m^3, please see Tables 4 and 11).

As we can see the method developed and presented in the methodological part of this project delivers reliable results for the first five years following the corresponding year 2005. But this positive impression can not be automatically transferred into the future. The problem is that data on forests provided by the most European countries mentioned in this Report are not consistent. This conclusion is arrived at after analysis of Net Annual Increment (in m^3 per hectare) given for the same years by two different

Reports, namely: State of Europe's Forests Report 2007 and State of Europe's Forests Report 2011.

Comparison of Net Annual Increment provided by countries for State of Europe's Forests Report 2007 and State of Europe's Forests Report 2011 is presented in Table 12.

Table 12: Net Annual Increment (in m^3 per hectare) provided to Forest Europe for State of Europe's Forests Reports 2007 and 2011 by countries mentioned in this Report

Country	Forest Europe 2007			Forest Europe 2011			
	1990	**2000**	**2005**	**1990**	**2000**	**2005**	2010
Austria	8.3	9.4	-	7.2	8.7	7.5	7.5
Belgium	7.7	8.0	7.9	7.7	8.0	7.9	7.9
Bulgaria	4.8	6.0	5.5	4.8	6.0	5.5	5.1
Czech Republic	6.6	7.7	8.1	7.3	8.4	9.0	9.9
Denmark	13.2	13.1	<u>13.4</u>	-	-	<u>9.5</u>	10.0
Estonia	5.9	5.4	5.3	6.1	5.6	5.5	5.6
Finland	3.5	3.9	4.6	3.6	4.0	4.5	4.6
France	6.0	6.7	6.9	6.0	6.7	6.9	6.2
Germany	-	11.1	-	12.2	11.5	11.5	10.1
Greece	1.3	-	-	1.3	-	-	-
Hungary	7.2	<u>7.2</u>	<u>7.7</u>	6.9	<u>5.7</u>	<u>5.8</u>	6.4
Ireland	-	-	-	-	-	-	-
Italy	3.5	3.8	4.3	4.1	4.1	4.1	4.0
Latvia	5.8	5.9	5.8	5.8	5.5	-	-
Lithuania	-	5.1	5.4	-	-	5.9	5.7
Luxembourg	7.6	7.5	7.5	7.6	7.5	7.5	-
Netherlands	7.8	7.7	7.6	7.8	7.7	7.6	7.6
Poland	-	-	8.0	-	-	8.0	-
Portugal	-	<u>6.4</u>	-	10.8	<u>10.7</u>	10.5	-
Romania	5.7	7.5	-	-	-	-	-
Slovakia	5.7	6.6	6.8	5.7	6.6	7.4	7.4
Slovenia	<u>4.5</u>	5.8	<u>6.3</u>	<u>5.4</u>	6.3	<u>7.1</u>	7.8
Spain	-	-	-	2.4	3.1	3.1	3.1
Sweden	4.2	4.3	4.3	4.1	4.1	4.5	4.7
UK	8.4	8.9	8.7	8.4	8.9	8.7	8.6

In Table 12 **bold** marked countries (8 countries) have provided for the same years the same numbers of NAI for the both of State of Europe's Forests Reports 2007 and 2011. For the other 16 countries some more or less significant differences are given in the numbers provided for Net Annual Increment. The most remarkable differences are underlined: for the year 2005, Denmark reported 13.4 m^3·ha^{-1} in Report 2007 but 9.5 m^3·ha^{-1} in Report 2011; in Hungary differences for the years 2000 and 2005 were 7.2 and 7.7 m^3·ha^{-1} (Report 2007) to 5.7 and 5.8 m^3·ha^{-1} (Report 2011); Portugal reported 6.4 and 10.7 m^3·ha^{-1} for the year 2000 in the two reports; in Slovenia the figures for the years 1990 and 2005 were 4.5 and 5.4 m^3·ha^{-1} in 2007 and 6.3 and 7.1 m^3·ha^{-1} in 2011. Ireland did not provide any data for either of the Reports.

It is also remarkable to see the back trends of NAI values for Denmark and Germany presented in Table 12. These high values of Net Annual Increment and NAI use have been already emphasized in Chapter 3.1 (Table 1, page 31) and in Grantholder Progress Report 2 / 2011.

In previous Grantholder Progress Reports 1 / 2010 and 2 / 2011 [8, 9] some more or less serious errors came into the light. The biggest technical error was made in Grantholder Progress Report 1 / 2010 where the Net Annual Increment for Spain was given as 1.6 $m^3 \cdot ha^{-1}$. Spain did not provide data on Net Annual Increment for the State of Europe's Forests Report 2007. However, it was possible to calculate the country's Net Annual Increment for the year 2000 from other data provided in the State of Europe's Forests Report 2007, and NAI value for this year have been estimated as 2.7 $m^3 \cdot ha^{-1}$ (please compare with values provided for State of Europe's Forests Report 2011 and given in Table 12). The value of 1.6 $m^3 \cdot ha^{-1}$ given in Grantholder Progress Report 1 / 2010 instead of 2.7 $m^3 \cdot ha^{-1}$ can be explained only through inattentiveness. However, this did not seriously influence the overall results and conclusions made in Grantholder Progress Report 1 / 2010 (please see Attachments) and was corrected during the work on Grantholder Progress Report 2 / 2011. Other differences occurring between previous Grantholder Progress Reports (corresponding years 2010 and 2011) are the results of rounding.

The method explained in the methodological part of this Report is based on fundamental ecological rules. It means that negative influences of technical errors and inconsistent data provided by National Forest Inventories on overall results and projections can be minimized should the method presented here be further developed.

At this stage of research the results achieved through applying the methodology developed here still depend very much on statistical (but at the same time also operational) data provided by National Forest Inventories. In its completed form this improved methodology can be used as a sustainability indicator of forest management practice in each particular case at local, regional or country scale.

4 Key findings from the work on project “Assessment and modeling of available forest resources in Europe for energy supply”

The following statements present in very compact form the key findings achieved during the work on project “Assessment and modeling of available forest resources in Europe for energy supply”:

1. Net Annual Increment can not be used to 100 percent. 100% NAI use does not correspond to the notion of sustainability in forest resources management.
2. From a very fundamental point of view we do not use (only) forest wood resources. We use products produced by sites with continuously changing growing conditions. By permanent forest ecosystem overuse the potential productivity of the site will be decreased.
3. Percentage of NAI use depends on existing site conditions and the ecological productivity of stands growing on given sites. First priority must be given to maintaining (or moderately increasing) the ecological productivity of forest stands. Only in exceptional (and carefully planned) cases can Net Annual Increment use be higher than 86.6 %.
4. To be able to estimate a level of sustainable use of renewable resources (in our particular case, percentage of annual increment use) we have to know two notions: site index and (ecological) class of site conditions. It means that in addition to Site Index (SI), the site conditions or Site Class (SC) has to be known (classified and estimated) for each forest stand or group of stands. As a base to work on this, the Ukrainian Ecological Site Conditions Classification [11] can be recommended here.
5. After work on this project it became possible to come to conclusion that not “business as usual” and not “mobilisation of forest wood resources” but **optimisation of forest management practice** is the key to sustainable forest wood resources supply. Already through on science-practice combined achievements based optimisation of forest management operations the forest sites ecological productivity and an annual forest wood resources supply can be significantly (but, once again, to affordable limit) increased.

5. Summary

Methodological part

During the work on project “Assessment and modeling of available forest resources in Europe for energy supply” a relatively simple method for estimation of sustainable level of forest wood resources use in Europe has been developed. The method is based on fundamental ecological rules and, despite its relative simplicity, can be applied at different spatial levels – local level, regional level, country level. Reliable results can be delivered for all three levels, but correspondence of achieved results and projections to the future realities will strongly depend on the consistency of data provided by forest practitioners and forest authorities. Data inconsistency will lead to the long term economical (underuse of available forest wood resources) or ecological (forest sites degradation) loss.

In the case of forests, we are dealing with long-existing but highly dynamic ecosystems. Mistakes made by forest practitioners at any stage of existence of the forest stand or group of stands can lead to significant economical and/or ecological losses in the future. That is why foresters in particular and also forest policy makers in general should be conservative up to some appropriate point. A permanent small underuse of a forest ecosystem’s resources is better than its permanent small overuse.

Results

The results delivered by this research are based on official data taken from the State of Europe’s Forests Report 2007 which data provided from countries for the year 2005. It means that 2005 has to be seen as the corresponding year for all above made projections.

According to State of Europe’s Forests Report 2007, 461 Mio m^3 wood, or 59.9 % of NAI (770 Mio m^3), have been supplied by 25 European countries from their forests available for wood supply in 2005. Potential wood supply, which would correspond to the notion of sustainability in forest management practice, is estimated to be 605 Mio m^3 per year, and corresponds to the use of 78.6 % of NAI (770 Mio m^3 in 2005). These calculations lead to the conclusion that an additional 144 Mio m^3 of wood could be supplied annually by European forests.

This existing volume of 144 Mio m^3 wood reserves does not mean its immediate availability for economical (material or energy) use. It is proposed in this Report that the next 40 years (2010 – 2050) are to be used for further structural improvements in Forest Sectors (in particular National Forest Inventories and Forest Management Systems) with the aim of making them more vital and able for guaranteed delivery of goods and services to economies under already existing constraints such as unfavourable climatic (read growing) conditions and continuous increase in wood demand. At the end of this time period European forests should be able to provide to the European economy 605 Mio m^3 wood annually (or more, if positive steps to increase sites productivity and forest area are taken).

It is projected that almost 230 Mio m^3 wood or near to 38 % of sustainable Net Annual Increment use (605 Mio m^3) can be supplied by European forests directly for energy use purposes. These numbers can of course vary depending on ecological, technical, or political constraints. But in all possible scenarios, it is not suggested to plan to harvest more than 44 % ($100 \times (1-(\cos 30)^4)$) from the total amount of sustainable Net Annual Increment use at European scale for direct energy use purposes. This 44 % in the corresponding year 2005 would make around 265 Mio m^3 wood supplies for energy purpose annually.

It is feasible to achieve a higher level of energy wood supply from European forests in the far future. For such a strictly planned case, additional measurements have to be elaborated in theory and implemented in practice. The maximal possible (but from author's point of view at this moment not sustainable) amount of wood which can be used directly for energy purposes at the European scale (25 countries in this Report) should not be more then 340 Mio m^3 annually ($770 \times 0.44 = 605 \times 0.56 = 338.8$ Mio m^3). A higher level of direct extraction of wood for energy from European forests will be neither economically nor ecologically sustainable.

This Report provides suggestions for sustainable forest wood resources use in 25 European countries on the basis of data available for the year 2005.

Recommendations

Depending on growing conditions, characterized mostly by water-temperature balance and nutritive elements availability, forests occupy a more or less remarkable position at the border between Lithosphere and Atmosphere. In turn forests play an exclusive role in the flow of water and nutritive elements. Exclusivity of this role, as has also been shown in this Report, has a spatial character.

This Report operates at the European scale and on this scale it makes sense to give only one recommendation which can be implemented at country level according to each country's particular growing conditions:

The spatial structure of landscapes and forests should be optimized according to existing growing conditions and then kept as near to the optimum as possible with respect social, technological, economical, etc. constraints; both those existing at the moment and those projected for the future.

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Attachments

Attachment 1

Key points of achieved preliminary results in Grantholder Progress Report 1

The results achieved in 2009 can be underlined by several key points.

A new method for estimation of an ecologically sustainable level of forest wood resources use has been developed. The mean annual increment is accepted as the basis of this method. It was assumed that 100% of annual increment may not be used and that the percentage of its use depends on site condition changes and the forest stand's productivity.

A first rough classification of geographical regions and sub-regions in Europe with countries belonging to these regions has been proposed. The critical ranges in mean annual increment by stable, positive and negative trended site conditions have been estimated. This estimation has to be further improved and applied with respect to climate change projections for already classified regions.

Theoretical levels of wood supply by ecologically sustainable wood resource use from forests available for wood supply, forests not available for wood supply and other wooded land have been calculated. These results should be seen as preliminary since they are based on the assumption that we have stable growing conditions for forests throughout the whole of Europe.

According to the study on Impacts of Climate Change on European Forests and Options for Adaptation, "the changes in average temperatures that forests will have to face over the next 100 years range, according to latest projections, between 2° C increase in Ireland and the UK, up to about 3° C increase in Central Europe and 4° C – 5° C increase in northern Boreal and parts of Mediterranean regions" (AGRI-2007-G4-06, Report to the European Commission Directorate-General for Agriculture and Rural Development [http://ec.europa.eu/agriculture/analysis/external/euro_forests/full_report_en.pdf]). According to the projections here mentioned, the theoretical levels of wood supply seem to mark the maximal possible in the future.

It is assumed at this stage of research that around 550 Mio m^3 (539.0-562.7 Mio m^3) of wood can be supplied by forests available for wood supply in Europe (EU-27 countries). Higher level of forest wood resources exploitation can lead to decrease of ecological sustainability of European forests.

First conclusions from Grantholder Progress Report 1

The North Europe region has already achieved its maximal possible level of wood supply (please compare real 180 Mio m^3 wood supply from FAWS in 2005 to the theoretical level of 175 Mio m^3). Increasing of forest stand productivity through improving site growing conditions and maintaining the ecological sustainability of forest are the most reasonable ways to increase or keep the present level of wood supply from the North European region.

The Middle Europe region is the "engine" at the present and will be in the future concerning amount of wood supply (please compare real ≈230 Mio m^3 wood supply from FAWS in 2005 to the theoretical level of 290 Mio m^3) and its quality. The share of wood supply from this region compared with the total wood supply from West Europe was around 50% and should grow in the future. Maintaining the ecological sustainability of already existing forest stands and increasing the area of forests available for wood supply (afforestation) are the ways to increase the amount of wood supplied by Middle Europe region.

Forests in the Southern Europe region will continue lose their share (at the moment ≈10%) of total volume of wood supply in Europe. The highest attention has to be paid to increasing the ecological role of the forests in the South of Europe. Maintaining the ecological sustainability of stands is the first priority for forest management practices in the South Europe region.

Applying sustainable forest management practices will make it possible to keep the wood supply from South-East Europe at the present level. The biggest potential in wood supply in this South-East Europe region is Romania.

It must be taken into account that the following countries have the highest level of Net Annual Increment and also the highest potential to increase wood supply in the near and far future: Denmark in North Europe region, UK and Ireland in north-west sub-region of Middle Europe region, Germany and Austria in Middle Europe region, and Romania in South-East Europe region. With the aim of sustainable wood supply into the far future, additional area for wood production should be mobilized, mostly in the Middle Europe region.

Conclusions to Grantholder Progress Report 2

A reliable method that respects forest ecosystem sustainability for estimation of potential wood supply from European forests in the near, middle and far future has been developed during the work on the ongoing project. This method is applicable either at local or country level. Site productivity and its potential changes with time should be seen as the core point of the method presented in this report.

The results presented in Grantholder Progress Report 2 can be seen as realistic. Potential fluctuations in estimations have to be taken into account, but these fluctuations can be easily minimised should the above explained method be applied at a local level where average site index and age structure of the stands are available.

In general, preliminary results and first conclusions made in Grantholder Progress Report 1 are approved by results presented in this Grantholder Progress Report 2. Recommendations made in the previous Report at a regional level (North Europe, Middle Europe, South-East Europe, South Europe) can be targeted now more precisely at country level. Such an opportunity gives us dependence between Net Annual Increment and percentage of NAI use presented in Figure 7 (Figure 7 in Grantholder Progress Report 2 corresponds to Figure 9 of this Final Report). According to this dependence, countries with low NAI have to make planned steps in the direction of increasing site productivity, while for countries with high NAI an increase in planned activity in afforestation can be suggested. Such a strategy will lead to a strengthened potential for additional wood supply from European forests in all the above mentioned time periods, but mostly in the middle and far future.

Sustainable forest management is “the must” for all countries. Permanent overuse of forest ecosystems’ potential in the near future can lead to substantial ecological and economical loss in the middle and far future.

It can be assumed on the basis of the above presented results that it is feasible to achieve approximately 30 % increase of annual wood supply from European forests in around 40-50 years time frame. Under this scenario ecological sustainability of forest ecosystems throughout Europe can be successfully maintained.

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Abstract

The project “Assessment and modeling of available forest resources in Europe for energy supply” has been led in the Institute for Environment and Sustainability of the European Commission Joint Research Centre in Ispra, Italy between April 2009 and March 2012. An innovative methodology for the estimation of a sustainable level of forest wood resources use has been developed during the work on the project. This methodology is built on fundamental ecological rules and can be applied at local, regional or country scales.

The results achieved in this Report are based on official data for the year 2005 provided by European countries to the FOREST EUROPE Ministerial Conference on Protection of European Forests in 2007. The year 2005 has to be seen as the corresponding year for all projections made in this Report. Most of the results presented in Chapter 3 are delivered through calculations made on the coefficients principle. This coefficients principle itself corresponds to the assumption that the level of renewable resources use depends on the ecological productivity of sites, which can differ very much at local and regional scale, or, as seen by the results presented in this Report, from one country to another.

Forests are extremely dynamic ecosystems which play an extraordinarily important ecological role. Since these ecosystems are under continuously growing environmental pressure, the methodology, results and recommendations made in this Report are strongly suggested to be further discussed, improved and implemented in appropriate form.

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